COMBINED LAND/SEA SURFACE AIR TEMPERATURE TRENDS, 1949-1972

by

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ABSTRACT

A major deficiency in most previous studies of fluctuations in the earth's climate based on air temperature records has been the dearth of data from oceanic areas and the Southern Hemisphere. This study analyzes a unique collection of ship-based observations of surface air temperature assembled by the U.K. Meteorological Office in parallel with the station-based dataset developed by the National Center for Atmospheric Research from the publications World Weather Records and Monthly Climatic Data for the World.

Based on this much more geographically comprehensive database, it is concluded that, during the 24-year period 1949-72, no statistically significant warming or cooling trends were evident in the time series of globally averaged surface air temperature measurements. However, temperature trends did vary latitudinally, with significant cooling in northern extra-tropical latitudes, no trend in equatorial latitudes, and significant but not homogeneous warming in southern extra-tropical latitudes. Time series of air temperatures over land and sea exhibited qualitatively similar behavior over the period 1949-72, indicative of both the comparable quality of the two datasets and the probable lack of significant widespread bias in the land-based measurements due to urban development.

The results of this study underscore the need for dense and geographically comprehensive measurements from both land and ocean areas and from both hemispheres in analyzing the global behavior of the earth's climate.

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I. INTRODUCTION

Over the past several decades, the behavior of the earth's climate as observed through surface air temperature (SAT) measurements has been the subject of considerable study. In general, most analysts have found long-term global or hemispheric average temperature fluctuations of about 0.5-1.0°C during the past century. This has fueled much speculation as to the causes and future course of such changes, especially in light of the possibility of human influences on climate (e.g., see SMIC, 1971; U.S. Committee for GARP, 1975; Geophysics Study Committee, 1977; World Meteorological Organization, 1979).

Most previous studies, however, have been based on one of only two distinct sources of data: 1) the World Weather Records (WWR) supplemented by the monthly publication Monthly Climatic Data for the World (MCDW) and 2) synoptic temperature maps published by the U.S.S.R. Main Geophysical Observatory (GGO) and by the U.S.S.R. Hydrometeorological Center. Unfortunately, even these two sources cannot be considered entirely independent since it is likely that they include data from many of the same stations. Furthermore, both data sources are subject to at least three major deficiencies. First, the observations are largely from only a limited portion of the globe, namely the Northern Hemisphere, which for various reasons has had longer-running and more densely spaced measurements. Second, the data are primarily from continental areas and sometimes a few islands and ship stations, ignoring vast areas of the oceans. Third, widespread artificial changes could be imbedded in the data due to local temperature trends arising from such influences as urban development and the movement of stations to airport sites. These deficiencies in existing global temperature datasets are especially critical because they raise serious doubts about whether the trends found in previous studies are indeed representative of the earth's climate as a whole. Geographic shifts in atmospheric circulation patterns, regional variations, or local influences could potentially be misinterpreted as major global climatic changes.

This study seeks to overcome the above deficiencies by the use of extensive ship observations of SAT's collected by the U.K. Meteorological Office. This dataset provides widespread coverage of the northern and tropical Pacific Ocean, the Atlantic Ocean, and the Indian Ocean for the period 1949-72. Few data exist in polar regions (poleward of 75^{o}N and 50^{o}S) and in some areas of the Pacific Ocean. Data after 1972 were not available at the time this analysis was begun. Nevertheless, this oceanic dataset provides a global-scale indication of the earth's temperature that is entirely independent from the data used in previous studies. It also increases substantially the total area of the globe with temperature measurements in both the Northern and Southern Hemispheres and should be free from the effect of urban development and thermometer movement.

In the analysis reported here, monthly and annual mean temperature trends for 5^{o}-wide latitude belts, regions, and the earth as a whole have been derived from data for land areas, oceanic areas, and combined land/ocean areas over the period 1949-72. These trends provide preliminary indications of the degree to which SAT trends for land and ocean correspond on both monthly and interannual time scales. They also form the basis for an independent test of the representativeness of temperature trends derived in other studies.

II. BRIEF REVIEW OF PAST STUDIES OF THE EARTH'S TEMPERATURE RECORD

Over twenty-five different studies of the global or hemispheric surface air temperature record have been conducted during the past three decades as listed in Table I.* This table lists all such studies reported in the formal literature available to the author arranged by date of first publication. Also included in the table are studies involving inferred tropospheric thickness (the geopotential height difference between two surfaces of constant barometric pressure). Publications by the same author or authors are grouped together unless significant changes were made in the data or analysis. Less than half of the studies include data from the Southern Hemisphere and about ten extend back to the previous century or earlier.

Table I illustrates the wide variety of analysis approaches that have been employed, including many different data-selection procedures, gridding and interpolation methods, and analysis techniques. However, as noted in the introduction, the primary data source in virtually all of the studies is either the WWR and/or MCDW or the GGO maps. One major exception is the study by Starr and Oort (5).** They used an independent but rather short-term (1958-63) set of daily radiosonde observations from the M.I.T. General Circulation Data Library (Starr and Oort, 1973; Oort and Rasmusson, 1971) to derive mass-average temperatures for the entire troposphere (1000 to 50 mb). Several other

* For a detailed review of early studies of temperature at individual stations or in limited areas, see Veryard (1963).

** Numbers correspond to studies listed in Table I.

Table I. Studies of the Earth's Instrumental Temperature Record of the Past Century Reported in the Formal Literature.

Study/Reference	Type of Temperature Series	Period and Time Unit	Latitudinal Coverage and Number of Stations	Grid and Interpolation Method	Data Sources*	Notes
1. Willett (1950)	5-yr deviations from 1935-40 stn. means	1845-1940; pentads (annual & winter)	70°S-80°N; 183 stns.	$10^{\circ} \times 10^{\circ}$**; 1 stn./ grid pt.	WWR (plus 4 other stns.)	a
2. Callendar (1961a)	deviations from 1901-30 stn. means	1870-1950; annual	60°S-73°N; over 400 stns.	latitude bands (60°S-25°S, 25°S-25°N, 25°N-60°N, 60°N-73°N); avg. of stns. in band	WWR (plus misc. stns.)	a
3. Mitchell (1961, 1963, 1970)	5-yr deviations from 1880-84 stn. means	1870-1960 (later to 1967); pentads (annual & winter)	60°S-80°N; 118-179 stns.	$10^{\circ} \times 10^{\circ}$**; 1 stn./ grid pt.	WWR, Scherhag (1965, 1966, 1967)	a
4. Budyko (1969, 1977); Spirina (1969, 1970)	deviations from long-term stn. means	1881-1960 (later to 1967); annual	20°N-80°N; stns. unknown	$5^{\circ} \times 10^{\circ}$**; map analysis	GGO	b
5. Starr & Oort (1973)	mass-average values & nonseasonal deviations for surface-75 mb	1958-63; annual & monthly	0°-90°N; ~300-600 stns.	$5^{\circ} \times 5^{\circ}$**; objective analysis	MIT	c

Table I (continued)

Study/Reference	Type of Temperature Series	Period and Time Unit	Latitudinal Coverage and Number of Stations	Grid and Interpolation Method	Data Sources*	Notes
6. Reitan (1974) (update of 1 & 3)	5-yr deviations from 1955-59 stn. means	1955-68; pentads (annual & winter)	0°-80°N; $\sim$200 stns. & misc. SST data)	10°-wide latitude bands; avg. of stns. in band	WWR, MCDW, misc. SST maps	d
7. Dronia (1974)	deviations from 1949-73 means for 1000-500 mb	1949-73; annual	25°-90°N; stns. unknown	$5^{\circ} \times 10^{\circ **}$; map analysis	FRG	e
8. Angell & Korshover (1975)	deviations from 1958-73 stn. means for 700-300 mb	1958-73; annual & seasonal	75°S-75°N; 45 stns.	latitude bands centered at 75°S, 45°S, 20°S, 20°N, 45°N, 75°N; avg. of stns. in band	MCDW	f
9. Yamamoto *et al.* (1975, 1978)	deviations from 1951-72 stn. means	1951-72; monthly	20°S-85°N; 343 stns.	$5^{\circ} \times 5^{\circ **}$; cubic spline	WWR, MCDW	
10. Brinkmann (1976) (update of 1, 3, & 5)	5-yr deviations from 1965-68 stn. means	1969-73; pentads (annual & seasonal)	0°-80°N; $\sim$200 stns. & misc. SST data)	10°-wide latitude bands; avg. of stns. in band	MCDW, misc. SST maps	g
11. van Loon & Williams (1976a, b), Williams & van Loon (1976)	means of stn. regression coefficients for overlapping 15-yr periods	1900-72; seasonal	15°N-80°N; $\sim$300 stns.	$5^{\circ} \times 5^{\circ **}$; map analysis	WWR	h

Table I (continued)

Study/Reference	Type of Temperature Series	Period and Time Unit	Latitudinal Coverage and Number of Stations	Grid and Interpolation Method	Data Sources*	Notes
12. Borzenkova *et al.* (1976)	deviations from long-term stn. means (corrected)	1881-1975; monthly	17.5°N-87.5°N; stns. unknown	5° x 10°**; map analysis	GGO	*i*
13. Damon and Kunen (1976)	means of stn. SAT observations for solar cycles & pentads	1943-74; solar cycles 1955-74; pentads	90°S-0°; 67 stns.	latitude bands (90°S-45°S, 45°S-35°S, 35°S-25°S, 25°S-0°); avg. of stns. in band	WWR, MCDW	*j*
14. Angell & Korshover (1977)	deviations from 1958-75 stn. means for surface, 850-300 mb, 300-100 mb, & surface-100 mb	1958-75; annual	90°S-90°N; 63 stns.	latitude bands (90°S-60°S, 60°S-30°S, 30°S-10°S, 10°S-10°N, 10°N-30°N, 30°N-60°N, 60°N-90°N); avg. of stns. in band	MCDW	
15. van Loon & Williams (1977)	same as 11, plus 700 mb temperature	1949-72; winter 1956-73; winter	15°N-80°N; 300 stns. 90°S-40°S; 24 stns.	5° x 5°**; map analysis	WWR, NMC	*k*
16. Kukla *et al.* (1977) (update of 7, 8, & 9)	same as 7, 8, & 9 (except base period of 1951-75 for 9)	7: 1949-76 8: 1958-76 NH 1958-75 SH 9: 1951-75 ann. 1965-75 seas.	same as 7, 8; 9: 30°S-90°N; 350 stns.	same as 7, 8, & 9	same as 7, 8, & 9	*e*, *f*

Table I (continued)

Study/Reference	Type of Temperature Series	Period and Time Unit	Latitudinal Coverage and Number of Stations	Grid and Interpolation Method	Data Sources*	Notes
17. Harley (1978)	deviations from 1959-65 and 1965-75 means for 1000-500 mb	1949-76; 12-mo. moving avgs.	25°N-85°N; stns. unknown	$5^\circ \times 5^{\circ**}$; map analysis	FRG, UK, CMC	l
18. Angell & Korshover (1978a)	deviations from 1958-77 stn. means for surface & surface-100 mb	1958-77; seasonal	90°S-90°N; 63 stns.	same as 14	MCDW	m
19. Barnett (1978)	deviations from 1950-77 stn. means	1950-77; annual & winter	15°N-65°N; 424 land & ocean stns.	$10^\circ \times 20^{\circ**}$; avg. of stns. in grid sq.	MCDW, TDF11	n
20. Yamamoto & Hoshiai (1979)	deviations from 1951-75 stn. means	1951-77; monthly	25°N-90°N; 370 stns.	$10^\circ \times 30^{\circ**}$ (45° at 80°N); optimum interpolation	WWR, MCDW, ATW	o
21. Harley (1980)	5-yr deviations between successive pentads for 1000-500 mb	1949-78; pentads	25°N-90°N (383 grid pts.); stns. unknown	$5^\circ \times 10^{\circ**}$; map analysis	FRG, UK, CMC	l
22. Yamamoto & Hoshiai (1980)	deviations from 1931-60 stn. means	1876-1975; seasonal	25°N-90°N; 367 stns.	same as 20	same as 20	o
23. Vinnikov _et al._ (1980)	deviations from long-term stn. means (recorrected)	1881-1978; annual	17.5°N-87.5°N; stns. unknown	$5^\circ \times 10^{\circ**}$; map analysis	GGO	p

Table I (continued)

Study/Reference	Type of Temperature Series	Period and Time Unit	Latitudinal Coverage and Number of Stations	Grid and Interpolation Method	Data Sources*	Notes
24. Boer & Higuchi (1980, 1981)	mean thickness for 1000-500 mb	1949-75; annual & seasonal	25°N-90°N; stns. unknown	$5^\circ \times 5^{\circ**}$; map analysis	UK	q
25. Navato *et al.* (1981)	deviations from 1958-78 stn. means for 700-300 mb	1958-78; monthly	90°S-82.5°N; 34 stns.	latitude bands (90°S-20°S, 20°S-20°N, 20°N-90°N); avg. of stns. in band	MCDW	r
26. Hansen *et al.* (1981)	deviations from long-term stn. means	1880-1979; annual	90°S-90°N; "several hundred" stns.	80 equal-area boxes; successive avg. of stns. in box	WWR, MCDW	s
27. Jones *et al.* (1981)	deviations from 1946-60 stn. means	1881-1980; monthly, seasonal, & annual	0°-90°N; 300-1300 stns.	$5^\circ \times 10^{\circ**}$; inverse-distance weight algorithm	WWR, MCDW, misc. stn. data	t

* for abbreviations, see ABBREVIATIONS AND SYMBOLS.

** latitudc by longitude.

Table I (continued)

Notes

a See also, Landsberg and Mitchell (1961), reply by Callendar (1961b), and Veryard (1963).

b According to Borzenkova *et al.* (1976), deviations for 1881-1940 were computed relative to the base period 1881-1935 for most stations and 1881-1940 for the remainder; and for 1941-60 relative to the base period 1881-1960.

c Observations taken at 0000 GMT. Interpolation to grid points using Conditional Relaxation Analysis Method. See Oort and Rasmusson (1971) for further details; also see Hawson (1974) and reply by Starr and Oort (1974).

d Used selected SST data as surrogate for SAT's in the Pacific Ocean. Data from Eber *et al.* (1968), the Japan Meteorological Agency, and the U.S. Bureau of Fisheries.

e Notes possible artificial cooling trend due to gradually improving radiosondes in the U.S.S.R.

f Observations normally taken at 1200 GMT. Stations selected at mean latitudes as given.

g As noted in d, but additional data from *Fishing Information* (National Marine Fisheries Service).

h Linear regression coefficients were calculated for station data for overlapping 15-year periods at 5-year periods. Coefficients were then plotted and zonally averaged.

i Basic data as in note b, plus deviations for 1961-69 were computed relative to the base period 1881-1935 and for 1970-75 relative to 1931-60. Corrections derived from anomaly maps (see Vinnikov *et al.*, 1980, for more details). See also, Budyko and Vinnikov (1976), Rubinshtein (1977), and Vinnikov (1977).

j Data classified as either urban or non-urban. See also, Carter (1978) and reply by Damon and Kunen (1978).

Table I (continued)

Notes (continued)

k Linear regression coefficients were calculated for station and 700 mb grid-point data for the entire 24-year series and then plotted and zonally averaged. 700 mb data are from daily maps prepared by the U.S. National Meteorological Center.

l Data for 1949-65 are from the Deutscher Wetterdienst via the U.K. Meteorological Office; for 1965-71 from the U.K. Meteorological Office; and for 1971-76(78) from the Canadian Meteorological Centre. Data from the Pacific Ocean is missing until 1966. Observations taken at 0300 GMT until 1957 and 0000 GMT thereafter.

m See update in Angell and Korshover (1978b) and data for 100-30 mb (42 stations).

n. Also used empirical orthogonal functions to analyze annual average temperature anomalies. Data as in note g. Ocean stations chosen on a 500-800 km grid.

o Optimum interpolation assumes zero deviation when no data exists at a grid point, causing underestimation of anomalies in data-sparse regions.

p Basic data and procedures as in note i, except a more complex system of corrections. Anomaly values were reread from maps with a slightly different grid (not specified).

q Basic data from the U.K. Meteorological Office. Observations taken twice daily. Pacific Ocean data south of 55°N missing before 1965. Cf. Harley, note l.

r Used method of Angell and Korshover (1975), with more limited station network and additional data checking.

s Used digitized version of WWR and MCDW data prepared at the National Center for Atmospheric Research (Jenne, 1975) with additional recent data from MCDW.

Table I (continued)

Notes (continued)

t As in r, plus additional data from CLIMAT network, Danish and Icelandic Meteorological Services, and miscellaneous Norwegian and Soviet sources. See also, Jones and Wigley (1980a,b,c,d) and Wigley and Jones (1981).

studies also derive tropospheric temperature changes, but do so indirectly from geopotential height data (7, 8, 14, 17, 21, 24, and 25). In some instances, sea surface temperature (SST) data from various sources were used as a surrogate for SAT measurements over the oceans (6, 10, and 19), but the degree to which these climatological parameters correspond is a major uncertainty. In many studies (e.g., 1, 2, 3, 20, 22, and 27), additional station data were also obtained from miscellaneous sources such as national meteorological services. Each of the principal data sources above, and the analyses that have been applied to them, warrant brief discussion.

World Weather Records/Monthly Climatic Data for the World

The *World Weather Records* contain monthly average temperature data from over 2500 individual stations around the world, with a few records that extend back as far as the early 1800's. Until 1940 they were published by the Smithsonian Institution (Clayton and Clayton, 1927, 1934, 1947) and from 1941-60 by the U.S. Department of Commerce, U.S. Weather Bureau (1959, 1965-68). More recently, global climatological data (including radiosonde observations) have been disseminated in *Monthly Climatic Data for the World* (U.S. Department of Commerce, 1961-present), a monthly publication produced under the auspices of the World Meteorological Organization. The dataset is now available in computer-readable form from both the National Climatic Center and the National Center for Atmospheric Research (Jenne, 1975).

Unfortunately, data coverage in the WWR and MCDW is neither geographically complete nor continuous in time. As Figures 1 and 2 (next chapter) illustrate for the period of interest in this study (1949-72), measurement stations are primarily located in continental areas, with some island sites and a few ship stations. Although the geographic coverage generally increases between Figures 1 and 2, the number of stations does decrease in a few squares, indicative of the transience of station records in the dataset. At least part of the lack of continuity may have arisen from the transition between the WWR and MCDW. Jones et al. (1981), for example, report a sharp drop in data coverage after 1960 due to the omission in MCDW of station records primarily from the tropics that had been reported in the WWR.

Several different methods have been used to compensate for irregular station spacing to avoid giving undue weight to data-rich regions. The simplest approach (used in studies 1, 3, 6, 8, 10, 14, 16, 18, and 25) is to develop a reasonably regular but coarse grid by carefully selecting one station to represent an area or grid point. Alternatively, data from all stations within the same grid square can be averaged together, using somewhat complicated algorithms or weighting schemes if desired (e.g., studies 2, 19, 26, and 27). A third approach is to interpolate data between stations to regular grid points using some interpolation method such as cubic splines or optimum interpolation (studies 5, 9, 16, 20, and 22). A major disadvantage of optimum interpolation is that grid points with no data are implicitly assigned an anomaly value of zero, leading to underestimation of the temperature trend (Yamamoto and Hoshiai, 1979, 1980).

The lack of continuous data at many stations raises the possibility of introducing false trends due to the addition or subtraction of station records. One method to avoid this problem, used by Damon and Kunen (13), is simply to select stations with records of equal length, employing some form of interpolation to fill in any missing data. However, most of the studies in Table I extract trend information by calculating temperature deviations or "anomalies" from the mean value over some base period at each station or grid point. The use of temperature anomalies has the added advantages of eliminating the need to adjust station temperature observations to the same altitude and of permitting the removal of the mean seasonal cycle from monthly or seasonal data. Alternatively, van Loon and Williams (11, 15) estimate the linear regression coefficients of station temperature data for successive but overlapping 15-year periods (at 5-year intervals). These coefficients were then interpolated to grid points by subjective map analysis and averaged zonally.

Soviet Dataset

The data and procedures used by Soviet analysts are reviewed in some detail by Jones *et al.* (1981). In brief, the Soviet studies (4, 12, and 23) essentially rely on monthly mean temperature maps for the Northern Hemisphere over the period 1881-1935, prepared by a group from the GGO (Sokhrina *et al.*, 1959). These in turn formed the principal basis for maps of temperature anomalies over the period 1881-1960 (Sharov, 1960-67). Maps of anomalies for 1961-75 were prepared by the U.S.S.R. Hydrometeorological Center (Gidromettsentr, 1961-78). Anomaly values were read off from the maps at regular grid points and used to compute zonal means.

The Soviet maps unquestionably include data from stations common to the WWR and MCDW, but the extent of overlap is not clear at this time. Information on the stations used to generate the original temperature and anomaly maps is not available, nor are the procedures for treating data-sparse areas and irregular station observations documented. As with the WWR and MCDW, it is clear that coverage of oceanic areas is poor. Moreover, the latitudinal coverage of the Soviet data (17.5^{o}N - 87.5^{o}N) is comparatively limited.

As indicated in detail in notes b and i of Table I, different base periods were used to compute the anomalies for different portions of the Soviet data. Borzenkova et al. (1976) developed a simple correction procedure to make anomalies more homogeneous without referring back to the original temperature data. Vinnikov et al. (1980) reread the anomaly values from the maps for the period 1891-1978 and recomputed the time series. They employed a slightly modified version of the correction procedure of Borzenkova et al. for continental grid points and a different procedure based on archives of air temperature normals for the remaining grid points. As pointed out by Jones et al. (1981), the uncorrected series of Budyko (4) and Vinnikov et al. (23) do differ noticeably, by roughly a tenth of a ^{o}C generally, but are still highly correlated (r = 0.98).

Tropospheric Temperature Data

Starr and Oort (5) took advantage of a comprehensive data archive at the Massachusetts Institute of Technology (MIT), compiled for a study of the atmospheric general circulation (see Oort and Rasmusson, 1971). This archive includes radiosonde observations made once daily at approximately 0000 GMT at nearly 600 stations in the Northern Hemisphere over the period 1958-63. Available daily data at the 1000, 950, 900, 850, 700, 500, 400, 300, 200, 100, and 50 mb levels were interpolated to regular grid points by an objective analysis algorithm and then averaged into monthly means and into mass-average values for the troposphere. The mass-average values thus incorporate considerably more temperature information than contained in just surface temperature measurements. However, the short period of this record limits its usefulness as an independent test of the other SAT datasets.

Various studies by Dronia (7, 16), Angell and Korshover (8, 14, 16, and 18), Harley (17, 21), Boer and Higuchi (24), and Navato *et al.* (25) extend the tropospheric time series by utilizing data on geopotential height differences. Dronia (1974) used monthly pressure charts prepared by the Deutscher Wetterdienst (FRG) as the basis for estimating free-air temperatures below 500 mb (roughly 5.5 km) at regular grid points. Harley (1978, 1980) performed a similar analysis with data from the U.K. Meteorological Office (which included some FRG data) and the Canadian Meteorological Centre (CMC). Boer and Higuchi (1980, 1981) essentially repeated Harley's analysis but with twice-daily data from the U.K. Meteorological Office. Angell and Korshover (1975, 1977, 1978a), in contrast, chose a sparse grid of 45-63 radiosonde stations reported in MCDW and derived time series for both free-air and surface temperature trends. Navato et al. (1981), in following the method of Angell and Korshover (1975), used even fewer stations than the latter, but more carefully scrutinized the observations and produced a monthly time series. In general, the above studies appear to have results consistent with each other and with Starr and Oort (5), although some differences in absolute values appear due to the different data bases and procedures.*

The utility of the tropospheric temperature trends as an independent check of the surface air temperature record is an unresolved issue. Tropospheric and surface air temperatures are controlled by different but interactive radiative and dynamic processes. Changes in atmospheric circulation patterns, for example, might involve large changes in surface air temperature with minimal changes in upper air temperatures (van Loon and Williams, 1977). In addition, radiosonde observations suffer from many of the same difficulties as surface measurements, including very scattered, land-based stations and possible measurement problems (e.g., see van Loon and Williams, 1976a; Hawson, 1974; Starr and Oort, 1974). Thus, although agreement between surface and tropospheric air temperature trends would be an encouraging sign, disagreement between them could arise for a variety of reasons that might be difficult to separate.

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* For example, see Angell and Korshover (1975), table I, and Harley (1978), table 2. Also, compare bottom two curves of Navato et al. (1981), figure 1, with Angell and Korshover (1975), figure 3.

Sea Surface Temperature Data

Studies by Reitan (6), Brinkmann (10), and Barnett (19) use SST data to increase the sampling of temperature in oceanic areas of the Northern Hemisphere. Reitan (1974) obtained SST data for the Pacific Ocean over the period 1955-68 from maps prepared by Eber et al. (1968), the Japan Meteorological Agency, and the U.S. Bureau of Fisheries (c.f., Newell and Hsiung, 1979). In his update of Reitan, Brinkmann (1976) added SST data for 1969-73 in both the Atlantic and Pacific Oceans. However, neither of these authors supply any indication of the geographic extent or treatment of these data in their published materials. Barnett (1978) combined extensive SST data from the "Marine Deck" (TDF11) maintained by the National Climatic Center with continental data from MCDW. His dataset includes almost as many oceanic stations as continental stations. He first calculated anomaly values for both land and sea data and then averaged values within each $10^{\circ} \times 20^{\circ}$ square. He also analyzed the spatial and temporal patterns of temperature variance by the use of empirical orthogonal functions, obtaining a coherent first eigenvector that correlates well ($r = 0.66$) with the hemispheric mean curve derived in his study.

All of these studies assume that SST's and SAT's are reasonably well correlated, at least on seasonal and annual time scales. This assumption is supported by the analyses of Newell and Weare (1976), Navato et al. (1981), Newell and Chiu (1981), and others. However, the latter studies also raise the possibility of connections between extra-tropical SAT's and tropical SST's and of lagged relationships between

SAT's and SST's. If borne out, these preliminary findings would greatly complicate the interpretation of temperature trends based on both SST's and SAT's. Moreover, SST data have their own potentially serious problems with respect to measurement biases and procedural changes (e.g., "intake" versus "bucket" temperature measurements; Barnett, personal communication, 1981). Further examination of this approach will clearly be necessary.

Comparison of Results

Despite the often substantial differences in data selection and analysis procedures described in the previous sections, all of the studies in Table I appear to have reasonably comparable results. Table II provides an admittedly simplistic comparison of the trends. Studies in this table are arranged in the same order as Table I. Temperature changes were estimated between single years (except as noted) to provide a rough indication of the sign and approximate magnitude of the trends. The years 1890, 1940, 1960, and 1970 were arbitrarily chosen to span periods of interest and ensure maximum possible overlap between studies.

For northern latitudes, the studies that extend back into the previous century (studies 1, 2, 3, 4, 12, 22, 23, 26, and 27) report a general warming of between 0.2°C and 0.7°C from 1880 to 1940. The low value by Yamamoto and Hoshiai (22) may have arisen from their use of optimum interpolation. Greater warming is apparent at higher northern latitudes and in winter in those studies with regional and seasonal breakdowns (e.g., see Mitchell, 1963, Table 5; Vinnikov _et al._, 1980, figure 1; and Wigley and Jones, 1980 a,d). From 1940 to 1960, the

Table II. Estimated Temperature Changes between Selected Years.*

Study/Reference	Layer	Region and Latitudes**	Temperature Change ($^{\circ}$C) 1890-1940	1940-1960	1960-1970	Source	Notes
1. Willett (1950)	surface	GL 70°S-80°N	+0.5	na	na	fig. 1	a
2. Callendar (1961a)	surface	GL 60°S-60°N	+0.41	na	na	Appendix	
		NX 25°N-60°N	+0.44	na	na	"	
		TR 25°S-25°N	+0.49	na	na	"	
		SX 60°S 25°S	+0.33	na	na	"	
3. Mitchell (1961, 1963, 1970)	surface	GL 60°S-80°N	+0.4	na	na	fig. 1(1961)	
		NH 0°-80°N	+0.6	-0.25	na	fig. 1(1970)	
		TR 30°S-30°N	+0.4	na	na	fig. 4(1961)	
		SH 60°S-0°	+0.4	na	na	fig. 1(1970)	
4. Budyko (1969)	surface	NX 20°N-80°N	+0.45	-0.15	na	fig. 1	
6. Reitan (1974)	surface	NH 0°-80°N	na	-0.2	na	fig. 1	b
7. Dronia (1974)	1000-500 mb	NX 35°N-90°N	na	na	-0.55	fig. 3	
8. Angell & Korshover (1975)	700-300 mb	NH 0°-75°N	na	na	-0.5	fig. 3	
		TR 20°S-20°N	na	na	-0.3	" "	
		SH 75°S-0°	na	na	-0.2	" "	
9. Yamamoto *et al.* (from Kukla *et al.*, 1976)	surface	NH 0°-90°N	na	na	-0.1	fig. 3/101	c
		TR 20°S-0°	na	na	0.0	fig. 3/104	c
10. Brinkmann (1976)	surface	NH 0°-80°N	na	na	-0.07	table 1	d
11. Williams & van Loon (1976)	surface	NX 15°N-80°N	na	-0.26	na	table 1	e

Table II (continued)

Study/Reference	Layer	Region and Latitudes**	Temperature Change (°C) 1890-1940	1940-1960	1960-1970	Source	Notes
12. Borzenkova *et al.* (1976)	surface	NX 17.5°N-87.5°N	+0.45	-0.10	0.0	fig. 1	
13. Damon & Kunen (1976)	surface	TR 25°S-0°	na	-0.01	-0.01	fig. 4e	f
		SX 90°S-45°S	na	na	+0.35	fig. 6	g
14. Angell & Korshover (1977, 1978)	surface	GL 90°S-90°N	na	na	-0.3	fig. 7	
		NX 30°N-90°N	na	na	-0.3	fig. 5	
		TR 30°S-30°N	na	na	-0.15	" "	
		SX 90°S-30°S	na	na	-0.7	" "	
	850-300 mb	GL 90°S-90°N	na	na	-0.1	fig. 7	
		NX 30°N-90°N	na	na	-0.4	fig. 5	
		TR 30°S-30°N	na	na	+0.05	" "	
		SX 90°S-30°S	na	na	-0.4	" "	
15. van Loon & Williams (1977)	surface	NX 20°N-80°N	na	na	-0.15	text	h
	700 mb	(winter)	na	na	-0.5	"	h
17. Harley (1978)	1000-500 mb	NX 25°N-85°N	na	na	-0.5	fig. 1	c
19. Barnett (1978)	surface	NX 15°N-65°N	na	na	-0.2	fig. 11	
20. Yamamoto & Hoshiai (1979)	surface	NX 25°N-90°N	na	na	-0.1	fig. 4b	c,i
21. Harley (1980)	1000-500 mb	NX 25°N-85°N	na	na	-0.3	table 1	j
22. Yamamoto & Hoshiai (1980)	surface	NX 25°N-90°N	+0.2	-0.05	-0.15	fig. 4	i

Table II (continued)

Study/Reference	Layer	Region and Latitudes**	Temperature Change ($^{\circ}$C) 1890-1940	1940-1960	1960-1970	Source	Notes
23. Vinnikov *et al.* (1980)	surface	NX 17.5°N-87.5°N	+0.47	-0.10	-0.07	table 2	
24. Boer & Higuchi (1980)	1000-500 mb	NX 25°N-90°N	na	na	-0.5	fig. 1	k
25. Navato *et al.* (1981)	700-300 mb	NX 20°N-82.5°N	na	na	-0.08	pers. comm.	l
		TR 20°S-20°N	na	na	+0.01	" "	l
		SX 90°S-20°S	na	na	-0.08	" "	l
26. Hansen *et al.* (1981)	surface	GL 90°S-90°N	+0.4	-0.05	-0.05	fig. 3	
		NX 23.6°N-90°N	+0.7	-0.1	-0.4	" "	
		TR 23.6°S-23.6°N	+0.3	0.0	0.0	" "	
		SX 90°S-23.6°S	+0.2	-0.1	+0.25	" "	
27. Jones *et al.* (1981)	surface	NH 0°-90°N	+0.48	-0.04	-0.21	table 1	

* Unsmoothed annual values for 1890, 1940, 1960, and 1970 obtained except as noted from tables in the cited reference if available or by visual inspection of figures (to 0.05°C if possible). Study numbers correspond to Table I. Only studies with published data are included.

** Abbreviations as given in ABBREVIATIONS AND SYMBOLS; however, the boundary between the tropics and extra-tropics is assumed to be roughly 20° ± 10°N or $^{\circ}$S.

Table II (continued)

Notes

a Temperature change between pentads 1890-94 and 1930-34.

b Temperature change estimated from curve of inter-pentadal mean temperatures.

c Annual values estimated visually from monthly data.

d Temperature change between periods 1960-64 and 1970-73.

e Temperature change between 1942 and 1972.

f Temperature change between solar cycles 23 (mid-1943 to mid-1953) and 24 (mid-1953 to mid-1963) for 1940-60 value and between solar cycles 24 and 25 (mid-1963 to mid-1974) for 1960-70 value.

g Temperature change between pentads 1960-64 and 1970-74.

h Winter temperature change estimated by assuming a linear decrease over the 24-yr. period 1949-72.

i Temperature change may be underestimated due to use of optimum interpolation.

j Temperature change between pentads 1959-63 and 1969-73.

k Assumed 20-meter change equals 1°C, as in Harley (1978).

l Monthly values for 1960 and 1970 averaged into calendar year values.

Northern Hemisphere trend reverses, with a general cooling of 0.04-0.25°C. This cooling appears to end in the mid-1960's, and in many of the studies a warming becomes noticeable by about 1970. For example, in figure 1 of Borzenkova *et al.* (1976), the northern extra-tropical temperature drops by almost 0.4°C from 1960-65, but by 1970 has regained the 1960 level. Notably, the cooling in the northern extra-tropical troposphere is generally larger than the surface cooling (see van Loon and Williams, 1977).

The general agreement among the studies in Table II regarding the temperature behavior of the Northern Hemisphere climate is supported by the analysis of Jones *et al.* (1981). They found high, significant correlations (with almost all coefficients greater than 0.70) among their Northern Hemisphere mean annual SAT trends and those of Budyko (1969), Reitan (1974), Yamamoto *et al.* (1975), Barnett (1978), Angell and Korshover (1978a), and Asakura* over periods for which these time series overlap. They note, however, that such high correlations should be expected because of the common source of raw station data.

Only a few studies present trends for the tropics. From 1890-1940, three studies (2, 3, and 26) report an increase of 0.3-0.49°C. Negligible change is apparent over the period 1940-60 (13, 26). However, examination of figure 3 of Hansen *et al.* (1981) shows that temperatures did decrease by about 0.05°C during this period, but regained the 1940 level

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* As reported in Angell and Korshover (1977) and U.S. Committee for GARP (1975). Otherwise, not formally published.

by 1960. A similar cycle occurs from 1960-70, leading to the low values for this period given in studies 8, 9, 13, 14, 25, and 26.

In southern latitudes, a warming of 0.2-$0.4^{\circ}C$ is apparent from 1890-1940 in studies 2, 3, and 26. From 1940-60, Hansen _et al._ (1981) indicate fluctuations of about $0.2^{\circ}C$, yielding a small net cooling of just $0.1^{\circ}C$. During the decade 1960-70, a disagreement as to the sign of the trend emerges among the different studies. Damon and Kunen (1976) and Hansen _et al._ (as well as this study) show a substantial surface temperature increase of a few tenths of a $^{\circ}C$, which appears to continue into the early 1970's.* In contrast, Angell and Korshover (1977) report a $0.7^{\circ}C$ surface temperature decrease, and Angell and Korshover (1975, 1977) and Navato _et al._ (1981) a 0.08-$0.4^{\circ}C$ tropospheric temperature decrease. The latter studies do indicate that the trend reverses to a warming in the early 1970's. The origin of this discrepancy, especially between the surface temperature curves of Angell and Korshover (1977; see also, 1978a) and those of Damon and Kunen (1976) and Hansen _et al._ (1981), is discussed further in the next chapter.

Summary

As evidenced by Table II, all of the previous studies of the earth's air temperature record do appear to agree qualitatively as to the general temperature behavior of the climate over the past century, with only one noticeable exception during 1960-70 in the Southern

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* See also, Tucker (1975), Salinger and Gunn (1975), and Salinger (1980).

Hemisphere. Estimates of the magnitude of the trends of course differ somewhat, as would be expected given the differing data sources and analysis procedures and the simple point estimates of trends used here.

It is important to note, however, that the general agreement among the studies in Table II could be the result of the large amount of data that they probably have in common. Most studies of the surface air temperature have drawn on the station measurements recorded in the WWR and MCDW, and several of the studies of tropospheric temperature use similar datasets. The latter, moreover, involve a very sparse network of upper-air observing stations. The sea surface temperature is an independent, densely measured climatological parameter, but its utility as a surrogate for air temperature is uncertain at present. SST data are also subject to other problems regarding possible false trends and measurement biases.

The past reliance on land-based station measurements of air temperature (or geopotential height) primarily from the Northern Hemisphere could lead to significant problems in understanding properly the behavior of the climate in both the past and the future. For example, as demonstrated by Parker (1981), if the air temperature over the land is greater than that over the sea, measurements restricted to land-based stations could greatly overestimate zonal mean temperature variations. Shifts in the mean position of troughs and ridges in zonal temperature patterns could generate apparent trends in land-based data that would not accurately represent the actual behavior of the zone or region. Similarly, excessive reliance on Northern Hemisphere data could be deceptive given that observations from only one region may not be representative of the earth's overall temperature behavior. Internal redistributions of heat within the climate system might, for example, result in warming in one region compensated by cooling in another. Finally, widespread measurements in land-based temperature measurements are possible due to such local but pervasive influences as urban development and its associated "heat island" effect and the movement of thermometers to airport sites (e.g., see Mitchell, 1953).

To help avoid the kinds of problems listed above, it is clear that some independent indicator of the earth's temperature behavior is needed. This thesis, in examining ship observations of air temperatures over the oceans, is an initial attempt to meet this need.

III. DATA ANALYSIS

In this thesis, use was made of two independent sets of SAT observations over the period 1949-72. Land data in the form of monthly averages were extracted from the World Monthly Surface Station Climatology maintained by the National Center for Atmospheric Research (NCAR) and based on the WWR and MCDW. Monthly sea data were obtained from the U.K. Meteorological Office, which collected ship observations of SAT's and averaged them into monthly values for $1^{\circ} \times 1^{\circ}$ grid squares. As described in this chapter, these two datasets were processed in a similar fashion to provide the highest practical compatibility. Efforts were also made to ensure comparability with the results of other studies.

Data Sources

As noted above, land observations of SAT's were obtained from a magnetic tape prepared at NCAR from the WWR and MCDW (Jenne, 1975; see also, Spangler and Jenne, 1977). Over the period 1951-70, this dataset contains temperature records from approximately 1700 stations with an average of about 10 months of data per year per station (see Jenne, 1975, Table 10-1). Monthly temperature means are recorded to the nearest $0.1^{\circ}C$ along with the numbers of observations per month. Information on station location, sources, altitude, and so forth are also included.

Maps of the numbers of stations in each $5^{\circ} \times 5^{\circ}$ grid square in 1949 and 1972 are given in Figures 1 and 2, respectively. Station coverage appears to increase generally over the period, although some squares do show decreasing numbers of stations. Some land and ship stations are included in the NCAR dataset and were kept as part of the land-based

Figure 1. Number of Stations with Data in Each 5° x 5° Grid Square: 1949.

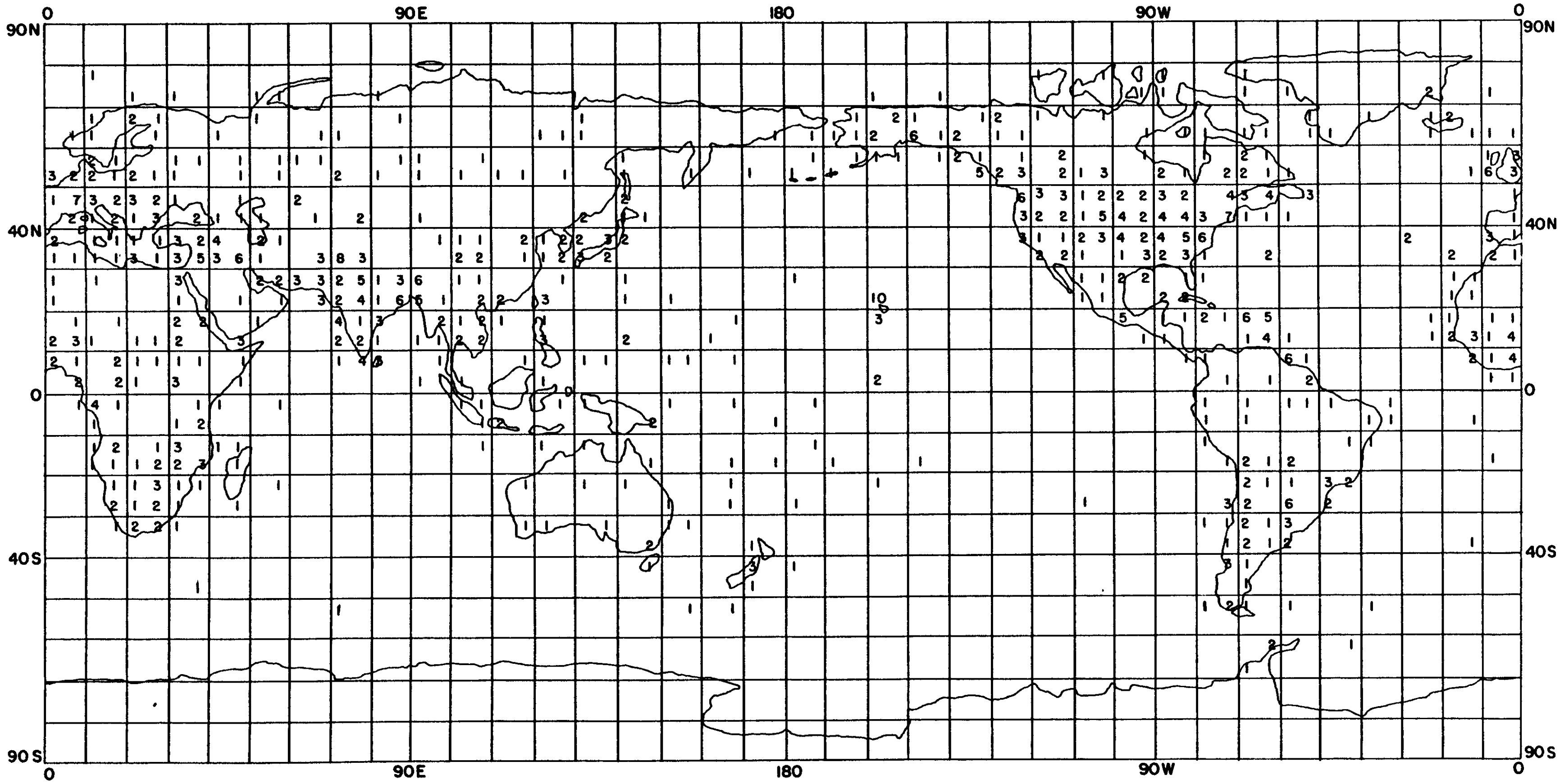
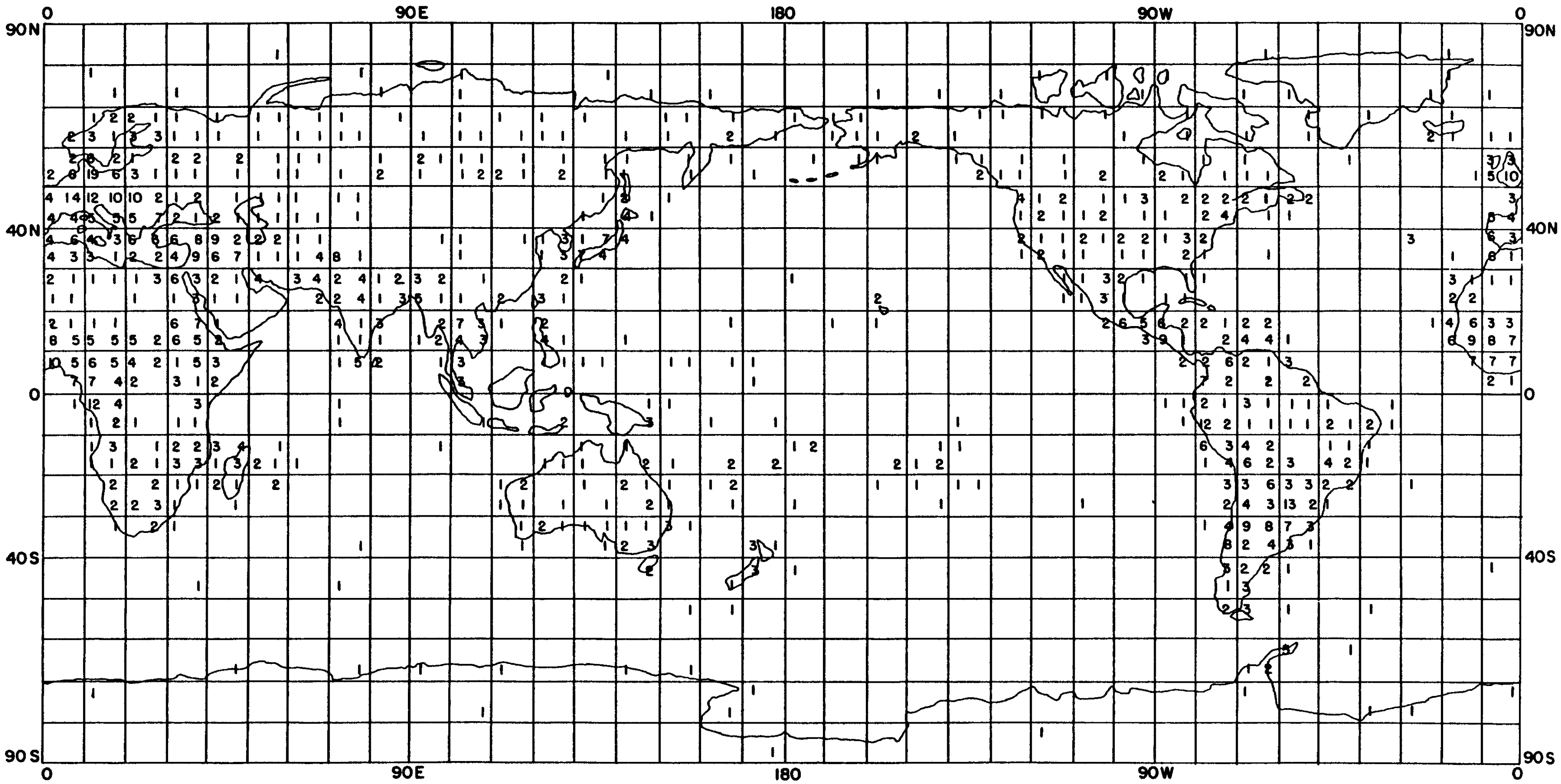


Figure 2. Number of Stations with Data in Each $5^{\circ} \times 5^{\circ}$ Grid Square: 1972.



analysis to ensure consistency with other studies. Clearly, there are substantially more stations in the Northern Hemisphere than in the Southern Hemisphere. Geographic coverage in the Southern Hemisphere is further limited by the high ratio of ocean area to land area.

Monthly mean SAT's over the oceans based on ship observations were obtained on magnetic tape from the U.K. Meteorological Office (personal communication, 1978, 1979). Monthly values for $1^{\circ} \times 1^{\circ}$ grid squares between 80°S and 80°N are recorded to the nearest 0.01°C along with counts of the numbers of observations per month. Data for December 1962 were incorrect on the original magnetic tape and were dropped from this analysis.

Figures 3 and 4 depict the average number of observations per month in each $5^{\circ} \times 5^{\circ}$ grid square over the period 1949-72 for the months January and July, respectively. In January, reasonably dense coverage is apparent from about 45°S to 70°N, while in July a small shift in coverage northward is noticeable. Observations are extremely dense in the North Atlantic and reasonably dense in the Indian Oceans and portions of the Pacific Ocean. Poor coverage is evident in the tropical and southeastern areas of the Pacific and in the South Atlantic. Areas north of about 75°N or south of about 50°S, which make up only about 5% of the total Northern Hemisphere oceanic area and about 22% of the Southern Hemisphere oceanic area, respectively, contain few observations.

A potentially important deficiency in the marine dataset is the low number of observations per month in many grid squares. The fewer the observations in a particular month, the larger is the potential sampling

Figure 3. Average Number of Temperature Observations per Month in Each Oceanic 5° x 5° Grid Square, 1949-72: January. Asterisks indicate an average of 100 or more observations per month in a grid square.

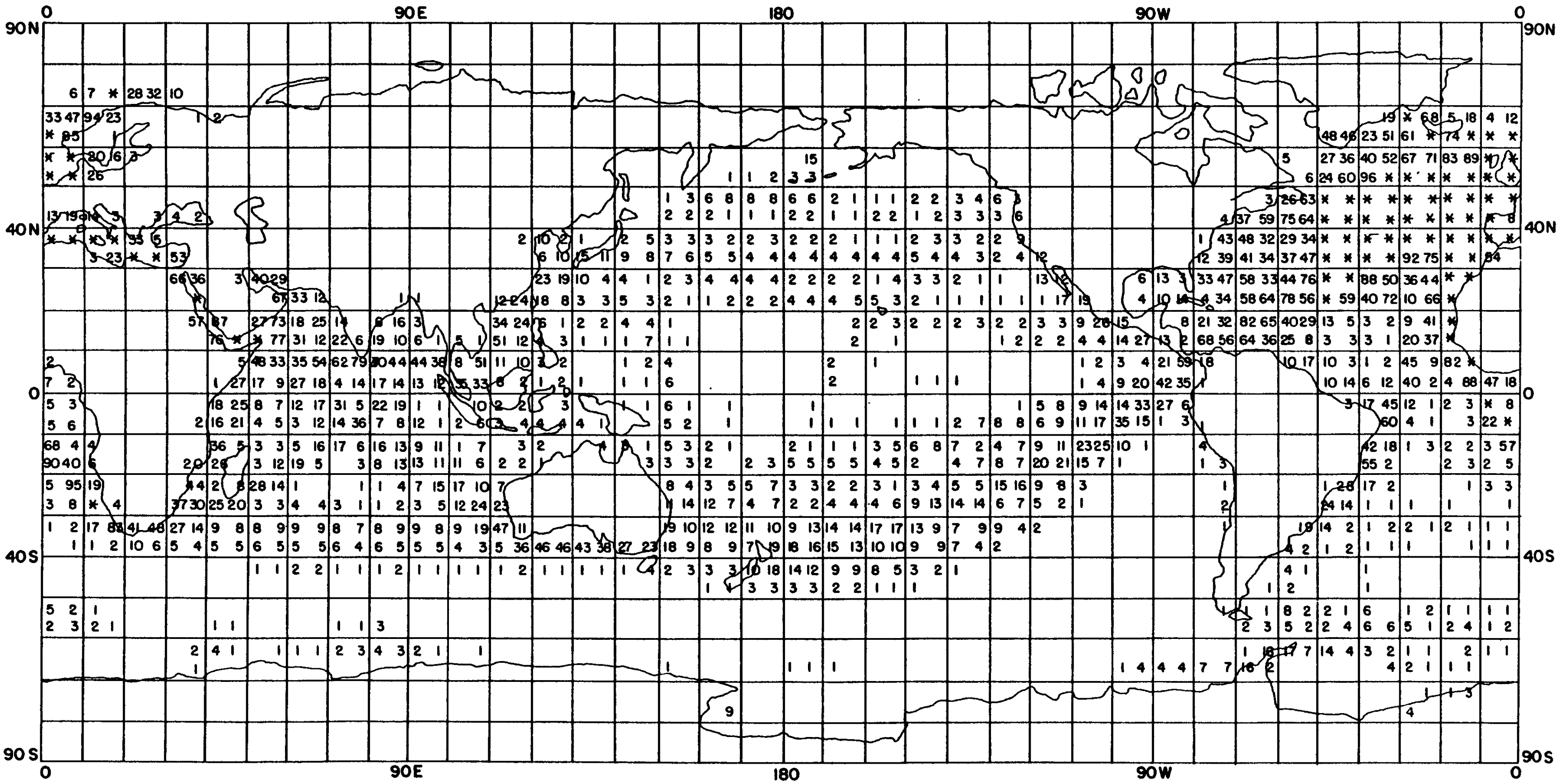
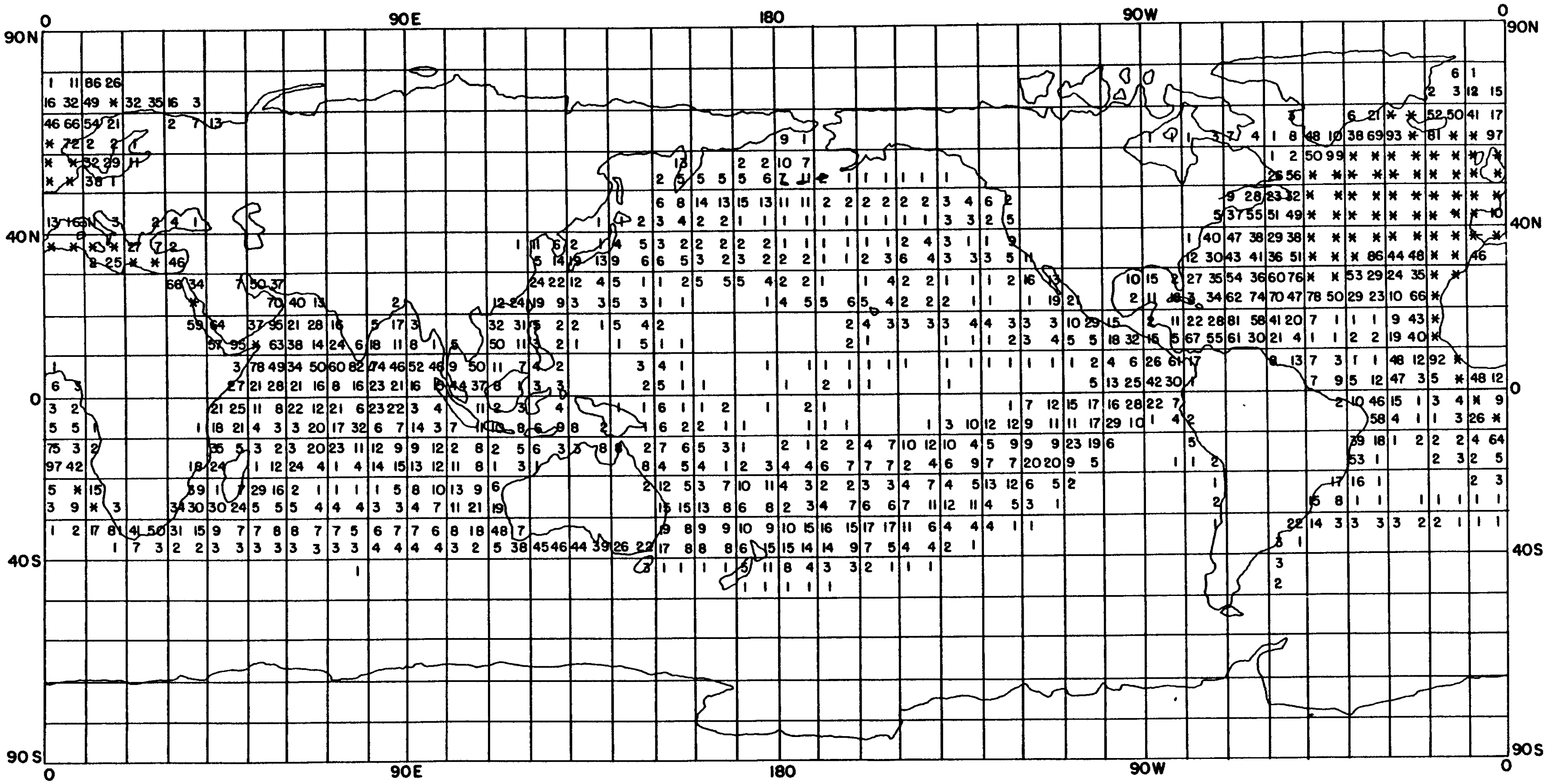


Figure 4. Average Number of Temperature Observations per Month in Each Oceanic 5° x 5° Grid Square, 1949-72: July. Asterisks indicate an average of 100 or more observations per month in a grid square.



error due to local, short-term temperature fluctuations within the month. However, omission of the grid squares with limited observations would entail substantial loss of geographical coverage, as evident from Figures 3 and 4, and indeed might introduce biases arising from the resulting preponderance of grid squares near coasts. On the other hand, the presence of significant daily auto-correlation, as found by several analysts for SAT and SST data (Newell, personal communication, 1981; Wigley, personal communication, 1981; see also, Madden, 1977), should decrease the sampling error considerably. Moreover, by averaging together many grid squares, the error should be reduced by at least a factor of the square root of the number of grid squares (assuming simplistically that the sampling error is the same in all grid squares and that these squares are not spatially correlated). Thus, although the time series for individual grid squares may be subject to large sampling error, the net error in time series for zones, regions, and the globe as a whole should be relatively less. Also, any such sampling errors would likely contribute only to the "noise" already present in the data, and not distort any "signal" (assuming that the errors are unbiased and random). In this analysis, grid squares with two or more observations per month are retained.

Analysis Procedure

Two primary objectives in this study were to develop:

a) consistent time series for land and sea SAT's, separately and in combination; and

b) time series comparable with previous studies.

It therefore appeared desirable to generate both monthly and annual time series averaged over zones (5^{o}-wide latitude bands), regions (the tropics and extra-tropics and the hemispheres), and the globe as a whole. The monthly time series can be used for detailed comparisons of land and sea data on monthly and seasonal time scales, while the annual data are more suitable for examination of long-term trends, especially as compared with other studies. The zonal time series permit close examination of the distribution of temperature change by latitude. The regional and global time series give an indication of the overall behavior of large areas of the globe.

The steps taken to generate monthly and annual time series for both land and oceanic data and for zones, regions, and the globe are summarized in equation form in Table III. Sections A and B of this table illustrate the procedures used for, respectively, the monthly and annual time series for the land-based (NCAR) data; sections C and D the procedures for the sea-based (UK) data; and sections E and F the procedures for the combined land/sea data. Small letters in this table indicate monthly values; capital letters indicate annual values. Marine data are distinguished by a single apostrophe, and combined land/sea data by a double apostrophe. Variable names and subscripts are defined in the table.

As noted in the previous chapter, most analysts derive anomaly values of temperature relative to the mean values of some base period to permit consistent averaging of station data. In this study, anomalies are generated from all available data for each station or 5^{o} x 5^{o} grid square during the period 1949-72 (eqns. A1, B2, C2, and D2). This

Table III. Equations Used in This Analysis.*

Land-Based (NCAR) Station Data

Monthly Analysis (Equations A1 - A4)

A1	$a_{ijk} = t_{ijk} - \dfrac{\sum_j t_{ijk}}{\sum j}$	for each month i, year j, and station k with data.
A2	$g_{ijl} = \dfrac{\sum_j a_{ijk}}{\sum k}$	for each month i and year j and all stations k with data in each grid square l.
A3	$z_{ijm} = \dfrac{\sum_l g_{ijl} * w_l}{\sum_l w_l}$	for each month i and year j and all grid squares l with data in each latitude band m (weighted by land area in each grid square l).
A4	$r_{ijn} = \dfrac{\sum_m z_{ijm} * w_m}{\sum_m w_m}$	for each month i and year j and all latitude bands m with data in each region (or globe) n (weighted by land area in each band).

Annual Analysis (Equations B1 - B5)

B1	$T_{jk} = \dfrac{\sum_i t_{ijk}}{12}$	for each year j of each station k with at least i=11 months of data (up to one missing month interpolated).
B2	$A_{jk} = T_{jk} - \dfrac{\sum_j T_{jk}}{\sum j}$	for each year j and station k with data.
B3	$G_{jl} = \dfrac{\sum_k A_{lk}}{\sum k}$	for each year j and all stations k with data in each grid square l.
B4	$Z_{jm} = \dfrac{\sum_l G_{jl} * w_l}{\sum_l w_l}$	for each year j and all grid squares l with data in each latitude band m (weighted by land area in each grid square).
B5	$R_{jn} = \dfrac{\sum_m Z_{jm} * w_m}{\sum_m w_m}$	for each year j and all latitude bands m with data in each region (or globe) n (weighted by land area in each band).

Table III (continued)

Sea-Based (UK) Data

Monthly Analysis (Equations C1 - C4)

C1	$t'_{ijl} = \dfrac{\sum_{k*} t'^{*}_{ijk*}}{k*}$	for each month i and year j and all $1^{o} \times 1^{o}$ grid squares k* with data in each $5^{o} \times 5^{o}$ grid square 1.
C2	$g'_{ijl} = t'_{ijl} - \dfrac{\sum_{j} t'_{ijl}}{\sum j}$	for each month i, year j, and grid square 1 with data.
C3	$z'_{ijm} = \dfrac{\sum_{l} g'_{ijl} * w'_{l}}{\sum_{l} w'_{l}}$	for each month i and year j and all grid squares 1 with data in each latitude band m (weighted by sea area in each grid square).
C4	$r'_{ijn} = \dfrac{\sum_{m} z'_{ijn} * w'_{m}}{\sum_{m} w'_{m}}$	for each month i and year j and all latitude bands m with data in each region (or globe) n (weighted by sea area in each band).

Annual Analysis (Equations D1 - D4)

D1	$T'_{jl} = \dfrac{\sum_{i} t'_{ijl}}{12}$	for each year j of each grid square 1 with at least i=11 months of data (up to one missing month interpolated).
D2	$G'_{jl} = T'_{jl} - \dfrac{\sum_{j} T'_{jl}}{\sum j}$	for each year j and grid square 1 with data.
D3	$Z'_{jm} = \dfrac{\sum_{l} G'_{jl} * w'_{l}}{\sum_{l} w'_{l}}$	for each year j and all grid squares 1 with data in each latitude band m (weighted by sea area in each grid square).
D4	$R'_{jn} = \dfrac{\sum_{m} Z'_{jm} * w'_{m}}{\sum_{m} w'_{m}}$	for each year j and all latitude bands m with data in each region (or globe) n (weighted by sea area in each band).

Table III (continued)

Combined Land/Sea Data

Monthly Analysis (Equations E1 and E2)

E1 $$z''_{ijm} = \frac{(z_{ijm} * w_m) + (z'_{ijm} * w'_m)}{w_m + w'_m}$$

for each month i, year j, and latitude band m with both land and sea data (value set to z if z' is missing and to z' if z is missing).

E2 $$r''_{ijn} = \frac{\sum_m z''_{ijm} * w''_m}{\sum_m w''_m}$$

for each month i and year j and all latitude bands m with data in each region (or globe) n (weighted by total land and sea area in each band).

Annual Analysis (Equations F1 and F2)

F1 $$Z''_{jm} = \frac{(Z_{jm} * w_m) + (Z'_{jm} * w'_m)}{w_m + w'_m}$$

for each year j and latitude band m with both land and sea data (value set to Z if Z' is missing and to Z' if Z is missing).

F2 $$R''_{jn} = \frac{\sum_m Z''_{jm} * w''_m}{\sum_m w''_m}$$

for each year j and all latitude bands m with data in each region (or globe) n (weighted by total land and sea area in each band).

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* Key:

t,T	temperature values (absolute; °C)
a,A	anomaly value for a land station k
g,G	anomaly value for a 5° x 5° grid square l
z,Z	anomaly value for a 5°-wide latitude band m
r,R	anomaly value for a region (or globe) n
w_l, w_m	proportion of land, sea, or total area in a grid square l or latitude band m
'	indicates sea data
"	indicates combined land/sea data

Note: $w''_l = w_l + w'_l$; $w_m = \sum_l w_l$; $w'_m = \sum_l w'_l$; $w''_m = \sum_l w''_l$.

approach minimizes the omission of station data due to incomplete records during a base period and has the added advantage that the anomaly values over the period of analysis sum to zero (within rounding errors). However, a disadvantage is that as new data are added, the entire time series must be recomputed.

Monthly anomalies were calculated by subtracting the long-term monthly average from each monthly value, thereby automatically removing the mean seasonal cycle (eqns. A1 and C2). Annual anomalies were derived from the monthly data by first calculating annual (calendar-year) values at each land station or $5^{\circ} \times 5^{\circ}$ oceanic grid square (eqns. B1 and D1). A linear interpolation was performed if a single monthly value was missing in a year. Years with more than one month missing were excluded. The annual time series thus contain slightly less station information than the monthly time series. A long-term annual mean was then calculated and subtracted from the annual values to form anomalies (eqns. B2 and D2).

To minimize biases due to the highly variable density of land stations, time series of station anomalies within the same $5^{\circ} \times 5^{\circ}$ grid square were averaged together (eqns. A2 and B3). Equal weight was given to each station regardless of its exact location within the grid square, since many squares contain only one station and tests with alternative weighting algorithms showed little difference in results.

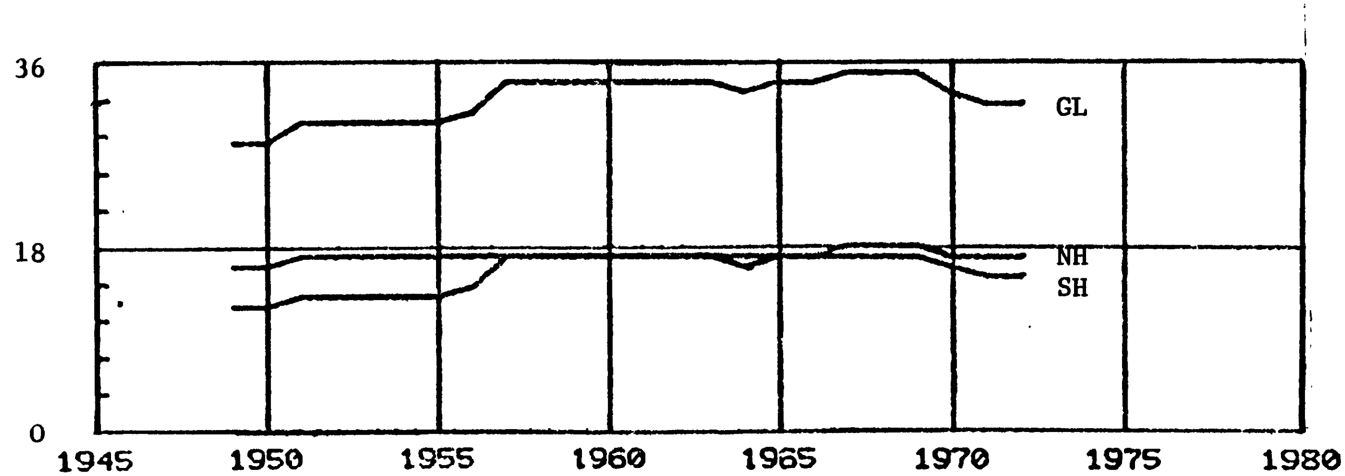
In the case of the sea data, the means for $1^{\circ} \times 1^{\circ}$ grid squares supplied by the U.K. Meteorological Office were averaged together into $5^{\circ} \times 5^{\circ}$ grid squares with equal weighting (eqn. C1) before rather than after the derivation of anomaly values (eqns C2 and D2). This procedure increases the likelihood of continuous time series within each $5^{\circ} \times 5^{\circ}$ grid square.

Zonal means for land and sea data were derived by averaging all available grid squares weighted by the proportion of land or sea area in each grid square (to the nearest 10%; eqns. A3, B4, C3, and D3). To form combined land/sea time series for each zonal band, the individual land and sea time series for the band were averaged together weighted by the overall proportion of land versus sea in the latitude band (eqns. E1 and F1). When either land or sea data were missing, the combined value was set to the remaining value. The weights used in all of these computations agree closely with the land/sea percentages given by Taljaard (1972).

Time series for regions and the globe as a whole were then calculated from all available zonal means weighted according to the land, sea, or total area in each zonal band (eqns. A4, B5, C4, D4, E2, and F2). The regions used were the northern extra-tropics (20°N - 90°N), the tropics (20°S - 20°N), the southern extra-tropics (90°S - 20°S), the Northern Hemisphere (0° - 90°N), and the Southern Hemisphere (90°S - 0°). Global means include all available latitude bands between 90°S and 90°N (see Figure 5).

The use of zonal means to form global and regional time series has two major advantages over other possible methods (e.g., averaging of all available grid squares). First, this procedure permits a more consistent representation of latitude bands in global and regional means on

Figure 5. Number of Latitude Bands in the Hemispheres and the Globe with Combined Land/Sea Data, 1949-72.

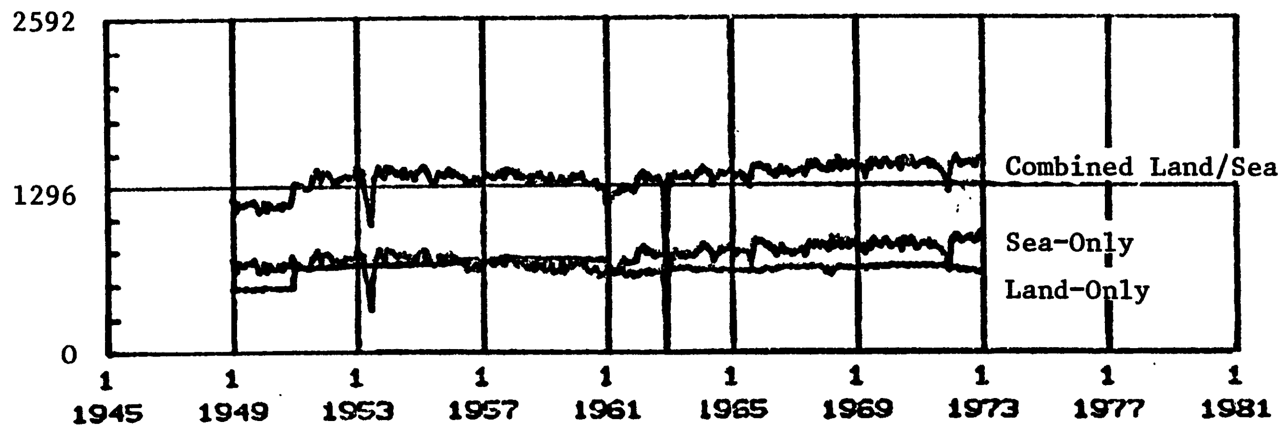


the basis of area, since otherwise undue weight would tend to be given to those bands with more data. Second, it takes advantage of the high proportion of latitude bands with data (see Figure 5). A potential disadvantage is that a few grid squares could unduly influence regional or global means because of the low number of squares in some latitudes; however, this problem is not expected to be significant since only the relatively low-area polar latitudes appear extremely data deficient.

It is interesting to compare the land-based, sea-based, and combined land/sea time series in terms of the number of grid squares with data. Figure 6 shows that only about half of the 2592 possible grid squares have either land data or sea data (or both). Assuming simplistically that all of these squares are in the lowest possible latitudes (i.e., latitudes of the greatest area per grid square), at least 29% of the earth's surface is not covered. Land and sea data provide approximately equal coverage in terms of numbers of grid squares.

To summarize, the analysis procedures used in this study entail the derivation of temperature anomalies for $5^{\circ} \times 5^{\circ}$ grid squares using all available data as a base period. Area-weighted zonal means were then calculated from grid squares and in turn formed the basis for area-weighted regional and global means. As will be seen in the next chapter, the procedures used in this study appear to generate results that are consistent with those of other studies.

Figure 6. Number of $5^{o} \times 5^{o}$ Grid Squares with Combined Land/Sea, Land-Only, or Sea-Only Data, January 1949 to December 1972,* for the Globe. The rather sharp changes in land data coverage in 1951 and 1961 apparently reflect publication discontinuities (c.f., Jones <u>et al.</u>, 1981, Fig. 1).



* December 1962 missing in sea-only data.

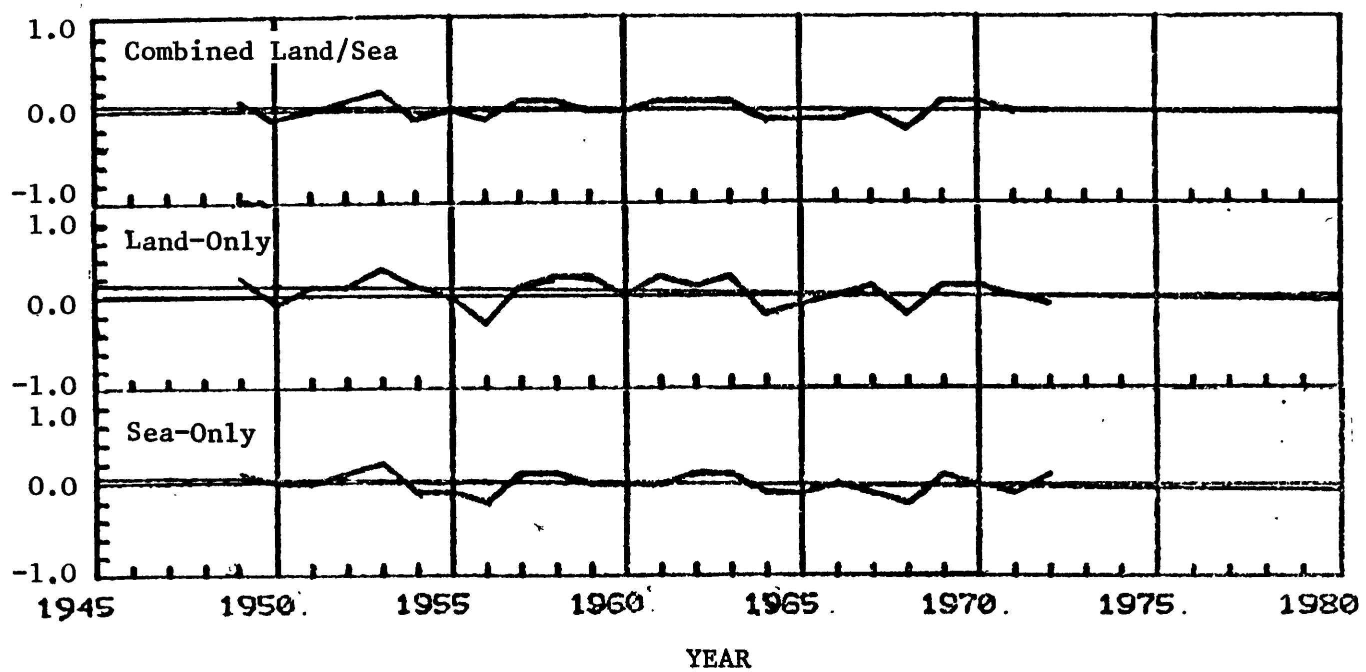
IV. ANNUAL TEMPERATURE TRENDS

The regional and global time series of annual SAT anomalies derived in this study are depicted in Figures 7 to 9 and tabulated in Appendix A. Trend lines are based on simple linear regressions and selected statistics accompany each plot. The t-statistic (T-STAT) is the ratio between the slope coefficient (SLOPE) and the standard error of estimate and tests the significance of the trend line (i.e., whether the slope is significantly above or below zero). Values greater than 2.508 indicate significance at the 99% confidence level for 22 degrees of freedom (using a one-sided statistical test) and greater than 1.717 at the 95% level. The 95% confidence level is taken to be the minimum level for "statistical significance" in this study. The Durbin-Watson statistic (DW) gives an indication of the degree of auto-correlation of the residuals of the linear regression and therefore of the independence of the observations. With 24 observations, values above 1.45 indicate no auto-correlation at the 95% confidence level while values below 1.27 indicate likely auto-correlation; values between these points are inconclusive (e.g., see Beals, 1972). If auto-correlation is present, the statistical significance of the trends and correlations becomes difficult to judge.

Comparison with Other Studies

The trends in Figures 7-9 and Appendix A appear reasonably consistent with the results of other studies as presented in Table II, although some differences are notable. From 1960 to 1970, the global

Figure 7. Annual Surface Air Temperature Anomalies for the Globe, 1949-72 (°C).



Combined Land/Sea:

SLOPE[a]	-0.002
T-STAT	-0.751
R-SQR	0.025
DW	1.95
STD DEV[b]	0.099

Land-Only:

SLOPE[a]	-0.006
T-STAT	-1.262
R-SQR	0.067
DW	2.00
STD DEV[b]	0.150

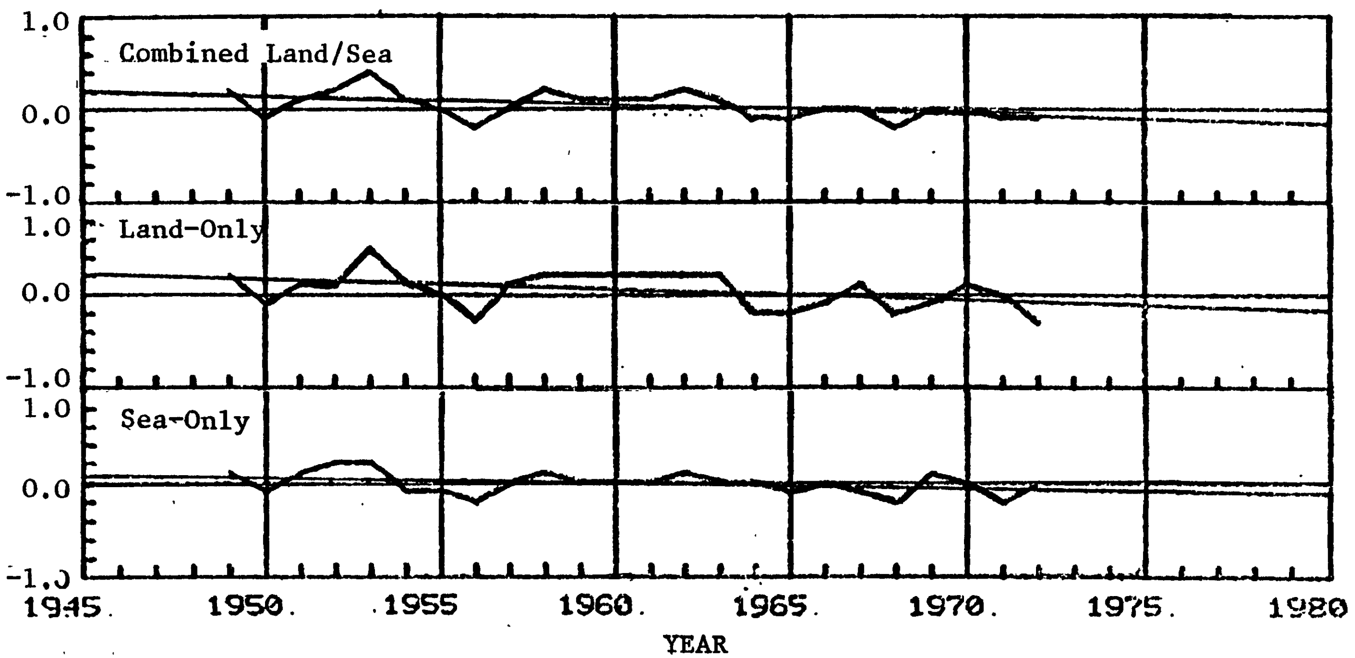
Sea-Only:

SLOPE[a]	-0.003
T-STAT	-0.998
R-SQR	0.043
DW	1.85
STD DEV[b]	0.106

[a] °C/yr. [b] °C

Figure 8. Annual Surface Air Temperature Anomalies for the Hemispheres, 1949-72 ($^{\circ}C$).

a) Northern Hemisphere (0° - $90^{\circ}N$)



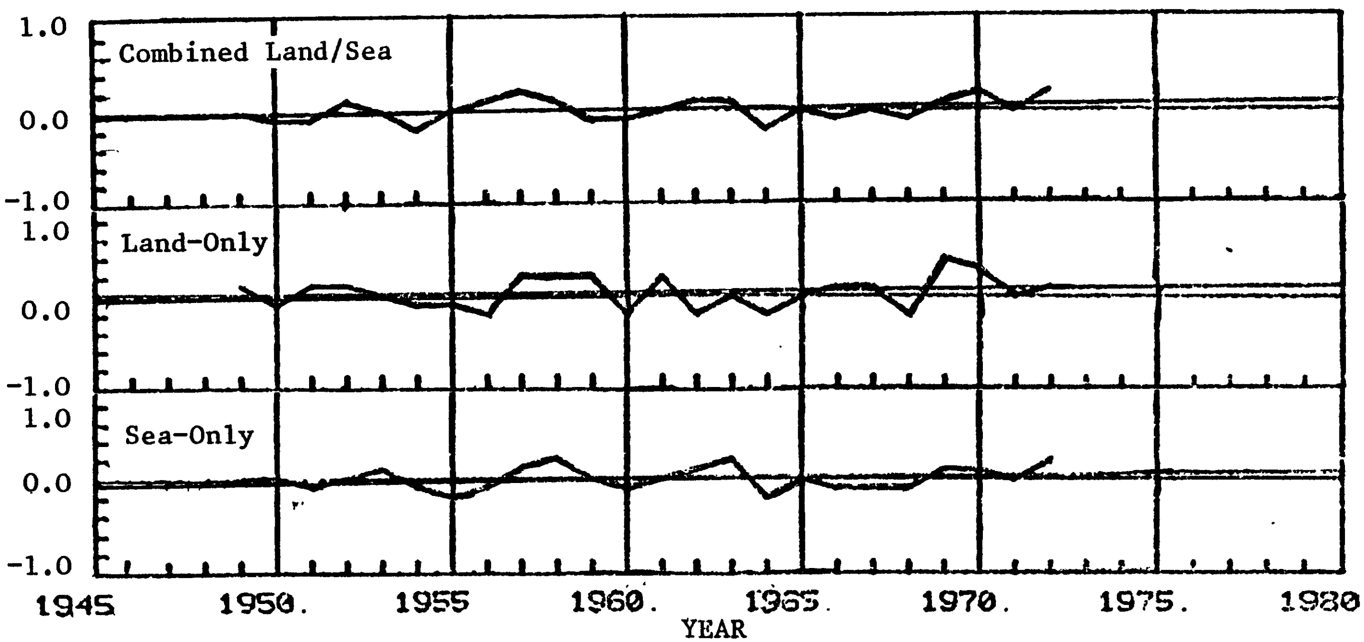
SLOPE[a]	-0.010
T-STAT	-2.571*
R-SQR	0.231
DW	1.55
STD DEV[b]	0.144
SLOPE[a]	-0.011
T-STAT	-2.064**
R-SQR	0.162
DW	1.58
STD DEV[b]	0.195
SLOPE[a]	-0.005
T-STAT	-1.636
R-SQR	0.108
DW	1.84
STD DEV[b]	0.114

[a] $^{\circ}C$/yr. [b] $^{\circ}C$ * significant at the 99% confidence level

** significant at the 95% confidence level

Figure 8 (continued)

b) Southern Hemisphere (90°S - 0°)

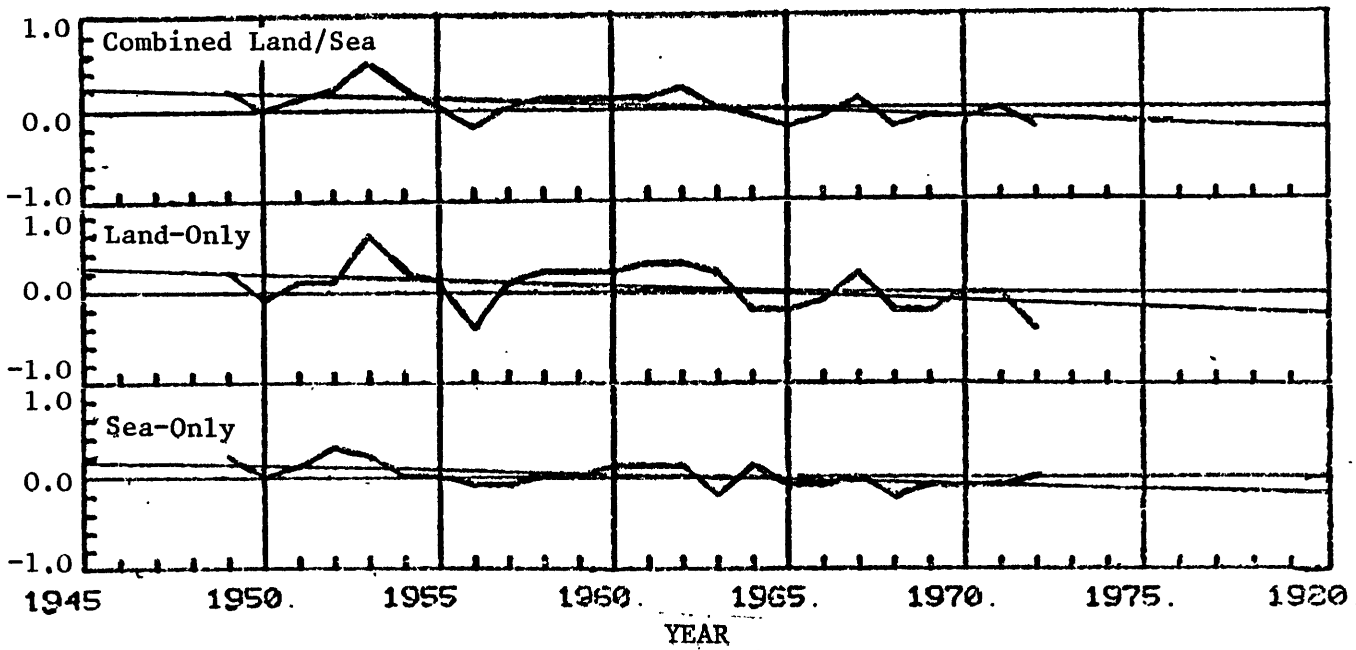


Combined Land/Sea	SLOPE[a]	0.004
	T-STAT	1.189
	R-SQR	0.060
	DW	1.73
	STD DEV[b]	0.176
Land-Only	SLOPE[a]	0.004
	T-STAT	0.857
	R-SQR	0.032
	DW	2.21
	STD DEV[b]	0.171
Sea-Only	SLOPE[a]	0.003
	T-STAT	0.992
	R-SQR	0.037
	DW	1.68
	STD DEV[b]	0.118

[a] °C/yr. [b] °C

Figure 9. Annual Surface Air Temperature Anomalies for Tropical/Extra-Tropical Regions, 1949-72 (°C).

a) <u>Northern Extra-Tropics</u> (20°N - 90°N)



SLOPE[a]	-0.014
T-STAT	-3.371*
R-SQR	0.341
DW	1.48
STD DEV[b]	0.168

SLOPE[a]	-0.014
T-STAT	-2.197**
R-SQR	0.180
DW	1.58
STD DEV[b]	0.238

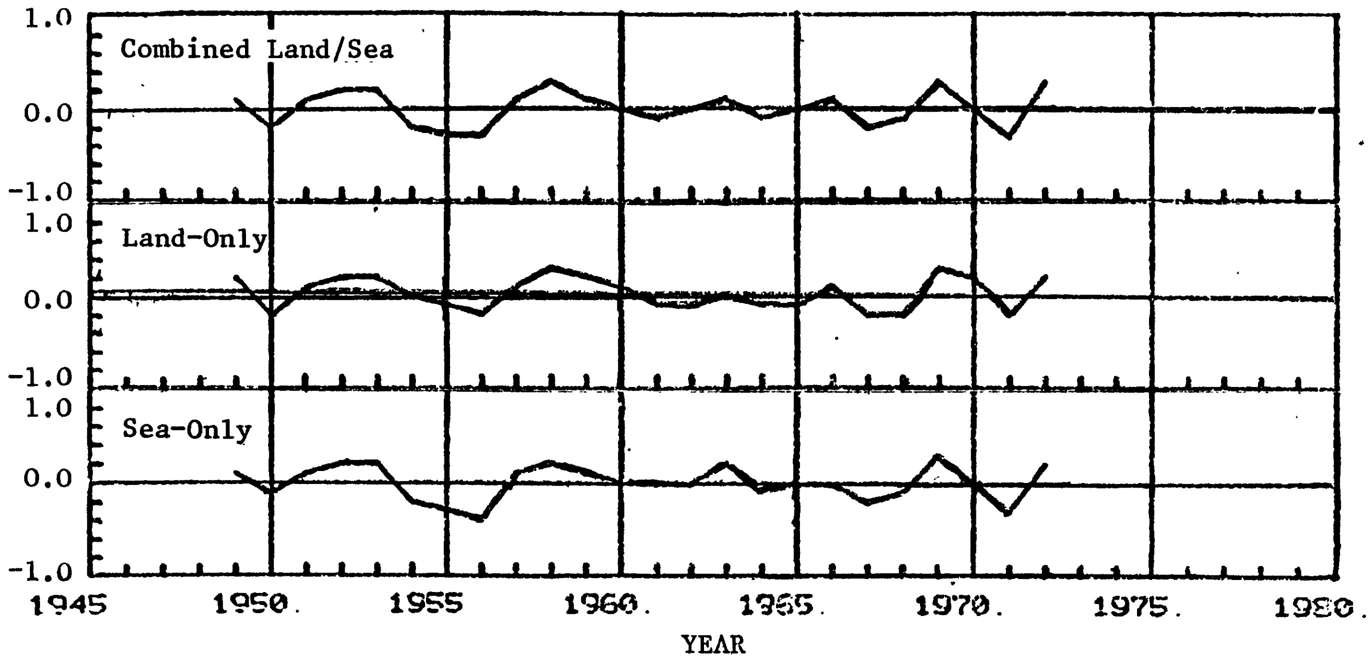
SLOPE[a]	-0.010
T-STAT	-3.295*
R-SQR	0.330
DW	1.85
STD DEV[b]	0.127

---

[a] °C/yr. [b] °C * significant at the 99% confidence level.
** significant at the 95% confidence level

Figure 9 (continued)

b) Tropics ($20^{o}S - 20^{o}N$)

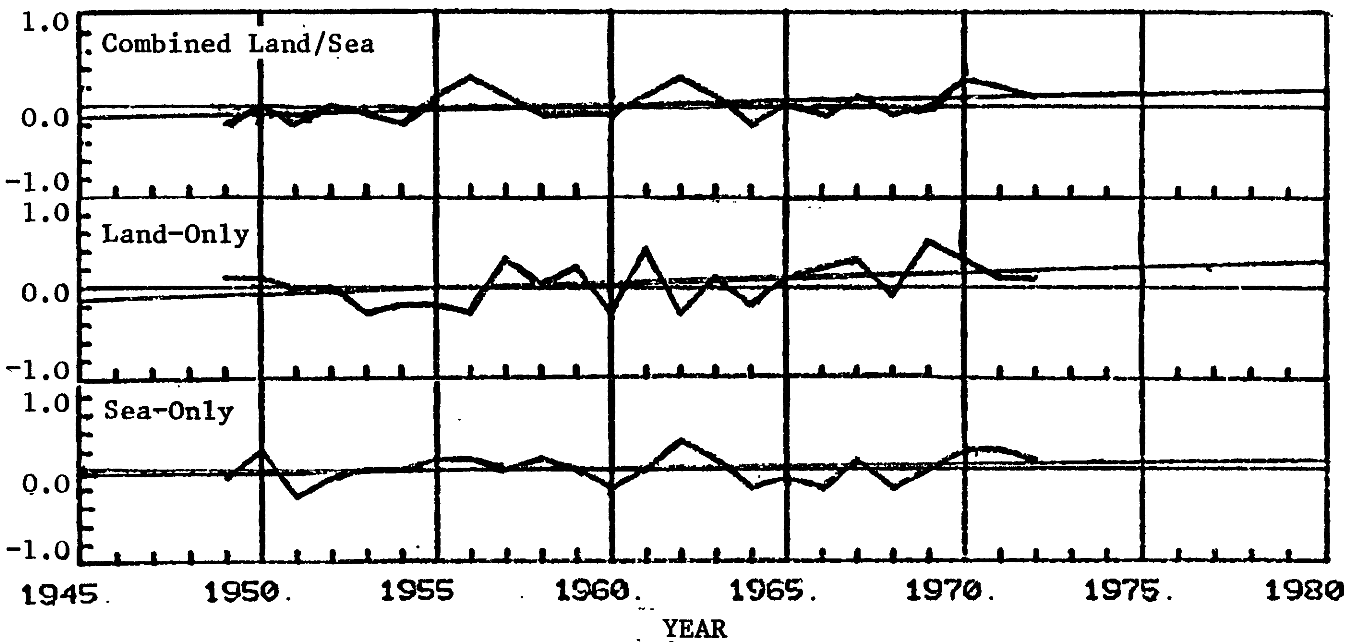


SLOPE[a]	0.001
T-STAT	0.160
R-SQR	0.001
DW	1.81
STD DEV[b]	0.190
SLOPE[a]	-0.003
T-STAT	-0.494
R-SQR	0.011
DW	1.82
STD DEV[b]	0.173
SLOPE[a]	-0.001
T-STAT	-0.110
R-SQR	0.001
DW	1.71
STD DEV[b]	0.184

[a] $^{o}C/yr$. [b] ^{o}C

Figure 9 (continued)

c) Southern Extra-Tropics ($90^{o}S - 20^{o}S$)



SLOPE[a]	0.009
T-STAT	1.946**
R-SQR	0.147
DW	1.61
STD DEV[b]	0.160
SLOPE[a]	0.012
T-STAT	1.834**
R-SQR	0.133
DW	2.53
STD DEV[b]	0.236
SLOPE[a]	0.004
T-STAT	0.824
R-SQR	0.030
DW	1.91
STD DEV[b]	0.155

[a] $^{o}C/yr$. [b] ^{o}C ** significant at the 95% confidence level

land-only temperature increased by 0.1°C, in contrast to the slight decrease reported by Hansen _et al._ (study 26, Table II) and the larger decrease of Angell and Korshover (14). However, examination of the regional trends illustrates that this global difference probably arises primarily from differences in the Southern Hemisphere. For example, the Northern Hemisphere land-only curve in Figure 8 exhibits a -0.1°C change from 1960-70 that is comparable to the surface temperature changes reported by Yamamoto _et al._ (9), Brinkmann (10), and Jones _et al._ (27). The decrease in northern extra-tropical temperatures (Figure 9a) is slightly larger (-0.2°C), consistent with the results of Borzenkova _et al._ (12), Angell and Korshover (14), van Loon and Williams (15), Yamamoto and Hoshiai (20, 22), Vinnikov _et al._ (23), and Hansen _et al._ (26). In southern latitudes, on the other hand, the surface warming of +0.5°C for the hemisphere as a whole and +0.6°C for the extra-tropics is somewhat greater than that reported by Damon and Kunen (13) and Hansen _et al._ (26) and, as noted previously, is in disagreement with the surface and tropospheric cooling of Angell and Korshover (8, 14) and Navato _et al._ (25). The tropical increase of 0.1°C also differs slightly from the no change or slight cooling reported by most other studies (8, 9, 13, 14, and 26) except Navato _et al._ (25). Interestingly, the one study with extensive data for the oceans by Barnett (19) shows exactly the same decrease of 0.2°C evident for the northern extra-tropical combined land/sea curve in Figure 9.

A more detailed comparison of northern-latitude trends over the period 1949-72 is possible in the case of studies by Vinnikov _et al._

(1980) and Jones *et al.* (1981),* as indicated by Figure 10 and Table IV. The slopes of the regression lines differ negligibly, by only 0.001 -0.003°C/yr. However, a much greater difference is apparent in the standard deviations (STD DEV), some 0.02-0.07°C, which is reflected in the different level of significance of the curves (95% in this study and 99% in the other two**). Correlations between the northern latitude land-only curves exceed 0.90 in both cases (Table IV). Indeed, the coefficient of 0.97 for the correlation between the curves of this study and Jones *et al.* equals or exceeds those reported by the latter with respect to other studies by Barnett (1978), Angell and Korshover (1975, 1978), Yamamoto *et al.* (1975), Reitan (1974), and Budyko (1969) for similar periods.

The close agreement among the curves in Figure 10 is perhaps surprising because of the substantial differences in analysis procedures used. As noted in Chapter II, Vinnikov *et al.* employed synoptic maps of temperature anomalies for the northern extra-tropics to interpolate data to grid points. Their mixture of base periods for 1949-72 (see Table I, notes *b*, *i*, and *p*) may be responsible to some degree for the 0.07°C difference in standard deviations. Jones *et al.* used the same basic dataset as this study with supplementary data from national meteorological services and other sources; however, their analysis procedures differed materially in several respects. First, they used a much more complex

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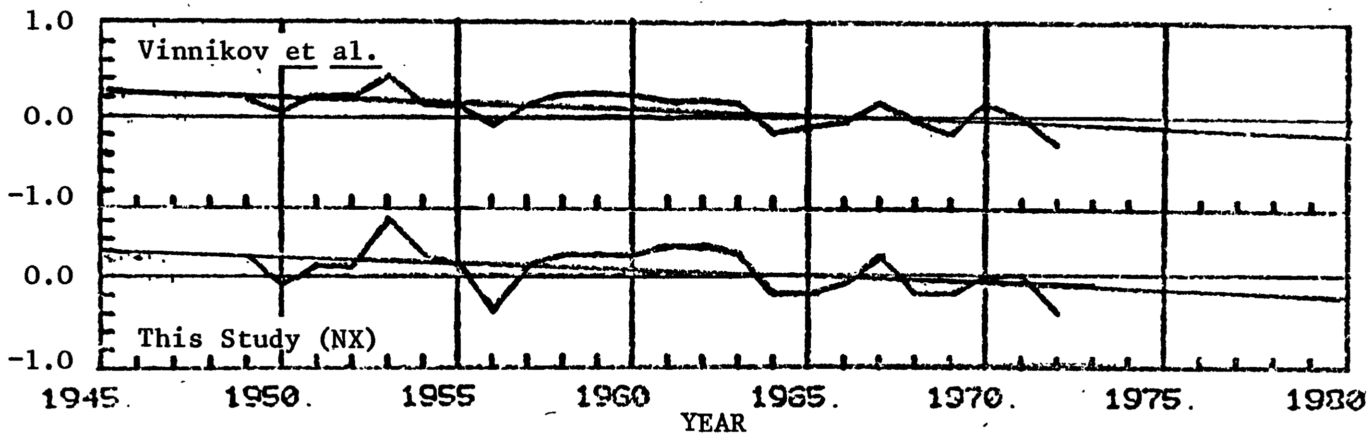
* The only two studies with tabulated data in their formal publications.

** The significance of the curve of Jones *et al.* may be somewhat less in actuality since significant auto-correlation may be present in their curve (see Figure 10b).

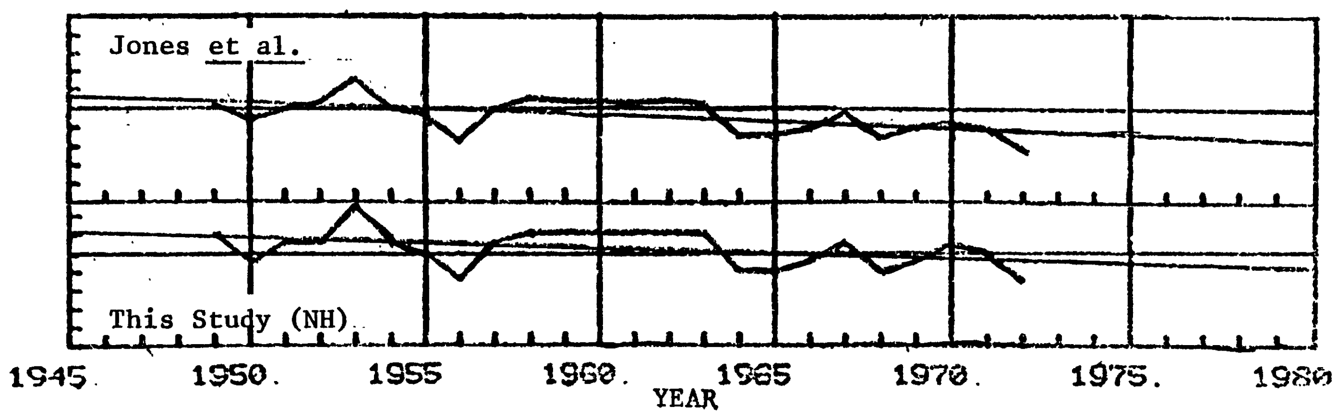
Figure 10. Comparison of Northern-Latitude, Land-Only Annual Surface Air Temperature Anomalies of This Study and Two Other Studies, 1949-72 (°C).

a) Vinnikov *et al.*, 1980 (17.5°N - 87.5°N)



SLOPE[a]	-0.013
T-STAT	-3.198*
R-SQR	0.317
DW	1.61
STD DEV[b]	0.168

b) Jones *et al.*, 1981 (0° - 90°N)



SLOPE[a]	-0.014
T-STAT	-3.048*
R-SQR	0.297
DW	1.37**
STD DEV[b]	0.176

[a] °C/yr. [b] °C * significant at the 99% confidence level **Durbin-Watson test ambiguous

Table IV. Correlation Coefficients between Annual Surface Air Temperature Anomalies of This Study and Two Other Studies, 1949-72 (Vinnikov et al., 1980, and Jones et al., 1981).

This Study	Vinnikov et al. (17.5°N-87.5°N) Land-Only	Jones et al. (0°-90°N) Land-Only
Northern Extra-Tropics (20°N - 90°N)		
Land-Only	0.910	na
Sea-Only	0.477	na
Combined Land/Sea	0.844	na
Northern Hemisphere (0° - 90°N)		
Land-Only	na	0.970
Sea-Only	na	0.618
Combined Land/Sea	na	0.918
Global (90°S - 90°N)		
Land-Only	0.855	0.748
Combined Land/Sea	0.691	0.553

method for interpolating station data to grid points (an inverse-distance weight algorithm) than used here. Second, they generated anomaly values relative to a base period of 1946-60 rather than to all available station data. Third, they formulated their Northern Hemisphere mean anomaly values by directly averaging all available grid squares instead of first forming zonal means as in this study.* Fourth, they derived annual deviations for the Northern Hemisphere by simple averaging of the monthly hemispheric anomalies rather than deriving anomalies from the annualized station data.** The similarity of results despite these substantial differences in procedures suggests that the interannual behavior of hemispheric land-only temperature may not be very sensitive to specific processing techniques, at least to the ones cited above. More important, as Table IV suggests, is whether or not data from tropical and southern latitudes and from oceanic areas are included in temperature trends.

Comparison of Regional Trends

Figure 7 illustrates that, for combined land/sea, land-only, and sea-only data over the period 1949-72, the surface air temperature of the earth as a whole evidenced only a slight cooling of a few thousandths of a ^{o}C per year. This trend is not statistically significant, i.e., the

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* This could explain their slightly lower standard deviation, since more grid squares are available at low latitudes where variability is less.

** An annual land-only curve was calculated in the same manner from the monthly time series derived in this study. The standard deviation of this curve is 0.190^{o}C, still slightly greater than the Jones *et al.* curve. The correlation between the two curves is 0.947.

T-STAT is lower than the value associated with the 95% confidence level. However, it is clear from Figure 8 and 9 that various regions of the globe behaved differently during this period. For example, the northern extra-tropics exhibited a statistically significant cooling trend of about $-0.014^{\circ}C/yr.$, which corresponds to the Northern Hemisphere cooling since the 1940's noted in Chapter II. The southern extra-tropics, on the other hand, evidenced a slight warming trend of about $0.01^{\circ}C/yr.$, statistically significant in the combined land/sea and land-only curves (Figure 9c). In the tropics, no significant trend is apparent (Figure 9b). Thus, the opposing trends of the northern and southern extra-tropics appear to balance each other to a considerable degree, yielding only a negligible trend globally. This finding is supported by the existence of slight negative correlations between the northern and southern extra-tropical curves as given in Table V. Interestingly, the Northern and Southern Hemisphere curves are not inversely correlated due to the inclusion of some tropical data in each hemisphere.

Whether the opposing behavior of the northern and southern extra-tropics is coincidental or due to some internal or external processes will clearly require a much more complete analysis to ascertain than is possible here. Such an analysis would need to incorporate dynamical considerations such as included in the studies of van Loon and Williams (1976a,b; 1977) and Williams and van Loon (1976). However, even without an analysis of this kind, it is possible to make two important inferences:

1) <u>Trends for particular regions may not be fully representative of the temperature behavior of the earth as a whole</u>. For

Table V. Correlation Coefficients between Annual Surface Air Temperature Anomalies for Regions, 1949–72.

Regions	Combined Land/Sea Data	Land-Only Data	Sea-Only Data
Northern vs. Southern Hemisphere	0.058	0.217	0.421
Northern vs. Southern Extra-Tropics	-0.273	-0.120	-0.201
Northern Extra-Tropics vs. Tropics	0.173	0.217	0.242
Tropics vs. Southern Extra-Tropics	-0.289	0.239	-0.199

example, correlation coefficients between the Northern Hemisphere curve of Jones _et al._ (1981) and the global land-only curve of this study is only 0.748 over 1949-72 (see Table IV). The correlations between the combined land/sea curves of this study for the Northern Hemisphere and the globe is 0.758 and for the Southern Hemisphere and the globe is 0.587. Use of either the Northern or Southern Hemisphere curve as a substitute for the global curve would lead to misestimations of the global trend by some 0.006-0.008°C/yr. and the global standard deviation by 0.045-0.077°C. This is of particular importance to attempts to determine whether or not temperature trends reflect external influences such as increased carbon dioxide heating of the atmosphere (e.g., Madden and Ramanathan, 1980; Wigley and Jones, 1981). As noted in Chapter II, differences between regional and global trends could arise, for instance, from internal redistributions of energy within the climate system (e.g., Schneider and Mass, 1975).

2) _Any attempt to use observed temperature trends to validate models of climatic change should take into account the regional nature of the trends._ This is especially important for models that involve external influences such as volcanic dust and anthropogenic emissions of carbon dioxide. Indeed, the ability of a particular model to explain regional differences in observed trends could be an important test of the extent to which significant internal processes and external forcings are properly accounted for in the model.

Comparison of Latitudinal Trends

Closer examination of the latitudinal distribution of temperature trends using the zonal data (in 5°-wide latitude bands) reveals several interesting features. Statistics for the zonal combined land/sea curves are given in Table VI. The slopes of the trend lines as a function of latitude for land-only and sea-only data are plotted in Figure 11.

Trends are consistently negative throughout the northern extra-tropics, with the strongest cooling north of about 60°N and statistically significant cooling between 30°N and 45°N. This compares well with the latitudinal distribution of trends by season reported by Williams and van Loon (1976, fig. 5), who show year-round cooling north of 55°N and between about 30°N and 45°N over the period 1942-72. The tropics exhibit consistently small trends, with all slopes less than 0.005°C/yr. in magnitude. However, in the southern extra-tropics, trends are not consistent in sign across all latitudes. Slight warming is evident from 20°S to 40°S, significant only in the trend for 35-40°S. From 40°S to 55°S a slight cooling is apparent, but is not statistically significant.* From 60°S to 85°S the trend reflects only land-based observations and shows slight warming, in agreement with other analyses of Antarctic station data by Budd (1975), Tucker (1975), and van Loon and Williams (1977). Finally, a slight but not significant cooling is apparent in the zone 85-90°S, based on the one station present (Amundsen-Scott Base); a similar cooling is reported by van Loon and Williams

* This contrasts with the warming in New Zealand stations reported by Salinger and Gunn (1975) and Salinger (1980).

Table VI. Selected Statistics for Combined Land/Sea Annual Surface Air Temperature Anomalies for Latitude Bands, 1949-72.

Latitude Band	SLOPE (^{o}C/yr)	T-STAT	R-SQR	DW	STD DEV (^{o}C)	CORREL	NOB
85-90^{o}N	NA	NA	NA	NA	0.462	NA	3
80-85^{o}N	-0.099	-3.634*	0.398	2.17	1.017	NA	22
75-80^{o}N	-0.047	-2.806*	0.264	2.14	0.643	NA	24
70-75^{o}N	-0.012	-0.688	0.021	2.44	0.601	0.270[b]	24
65-70^{o}N	-0.021	-1.454	0.088	2.02	0.503	0.215[b]	24
60-65^{o}N	-0.019	-1.455	0.088	2.15	0.462	0.203[b]	24
55-60^{o}N	-0.010	-1.000	0.043	2.09	0.345	0.263	24
50-55^{o}N	-0.010	-1.065	0.049	2.14	0.314	0.317	24
45-50^{o}N	-0.008	-0.867	0.033	1.87	0.276	0.238	24
40-45^{o}N	-0.013	-2.287**	0.192	1.54	0.206	0.113	24
35-40^{o}N	-0.019	-4.813*	0.513	1.63	0.186	0.253	24
30-35^{o}N	-0.011	-2.909*	0.278	1.50	0.148	0.295	24
25-30^{o}N	-0.006	-1.572	0.101	2.04	0.127	0.291	24
20-25^{o}N	-0.005	-1.003	0.044	1.63	0.157	0.446	24
15-20^{o}N	0.001	0.259	0.003	2.13	0.173	0.602	24
10-15^{o}N	-0.001	-0.157	0.001	2.01	0.184	0.708	24
5-10^{o}N	-0.000[a]	-0.074	0.000[a]	1.99	0.195	0.791	24
0- 5^{o}N	-0.003	-0.512	0.012	2.00	0.201	0.549	24
0- 5^{o}S	0.004	0.534	0.013	2.14	0.266	0.595	24
5-10^{o}S	-0.002	-0.270	0.003	1.66	0.220	0.607	24
10-15^{o}S	0.001	0.217	0.002	1.64	0.213	0.367	24
15-20^{o}S	-0.002	-0.401	0.007	1.76	0.184	0.334	24
20-25^{o}S	0.005	1.147	0.056	1.79	0.158	0.248	24
25-30^{o}S	0.001	0.132	0.001	1.87	0.196	0.034	24
30-35^{o}S	0.008	1.691	0.115	1.62	0.173	0.046	24
35-40^{o}S	0.016	2.788*	0.261	1.34[c]	0.220	0.205	24
40-45^{o}S	-0.011	-1.113	0.053	2.04	0.334	0.137[b]	24
45-50^{o}S	-0.003	-0.295	0.004	2.07	0.289	0.204[b]	24
50-55^{o}S	-0.000[a]	-0.028	0.000[a]	2.18	0.314	NA	24
55-60^{o}S	NA	NA	NA	NA	NA	NA	0
60-65^{o}S	0.010	0.279	0.004	1.47	1.052	NA	22
65-70^{o}S	0.068	1.767**	0.135	1.21[d]	1.198	NA	22
70-75^{o}S	0.009	0.150	0.002	1.83	0.894	NA	12
75-80^{o}S	0.033	1.019	0.065	1.73	0.656	NA	17
80-85^{o}S	0.043	0.649	0.037	1.71	0.869	NA	13
85-90^{o}S	-0.032	-0.430	0.013	2.23	1.319	NA	16

* significant at the 99% confidence level.

** significant at the 95% confidence level.

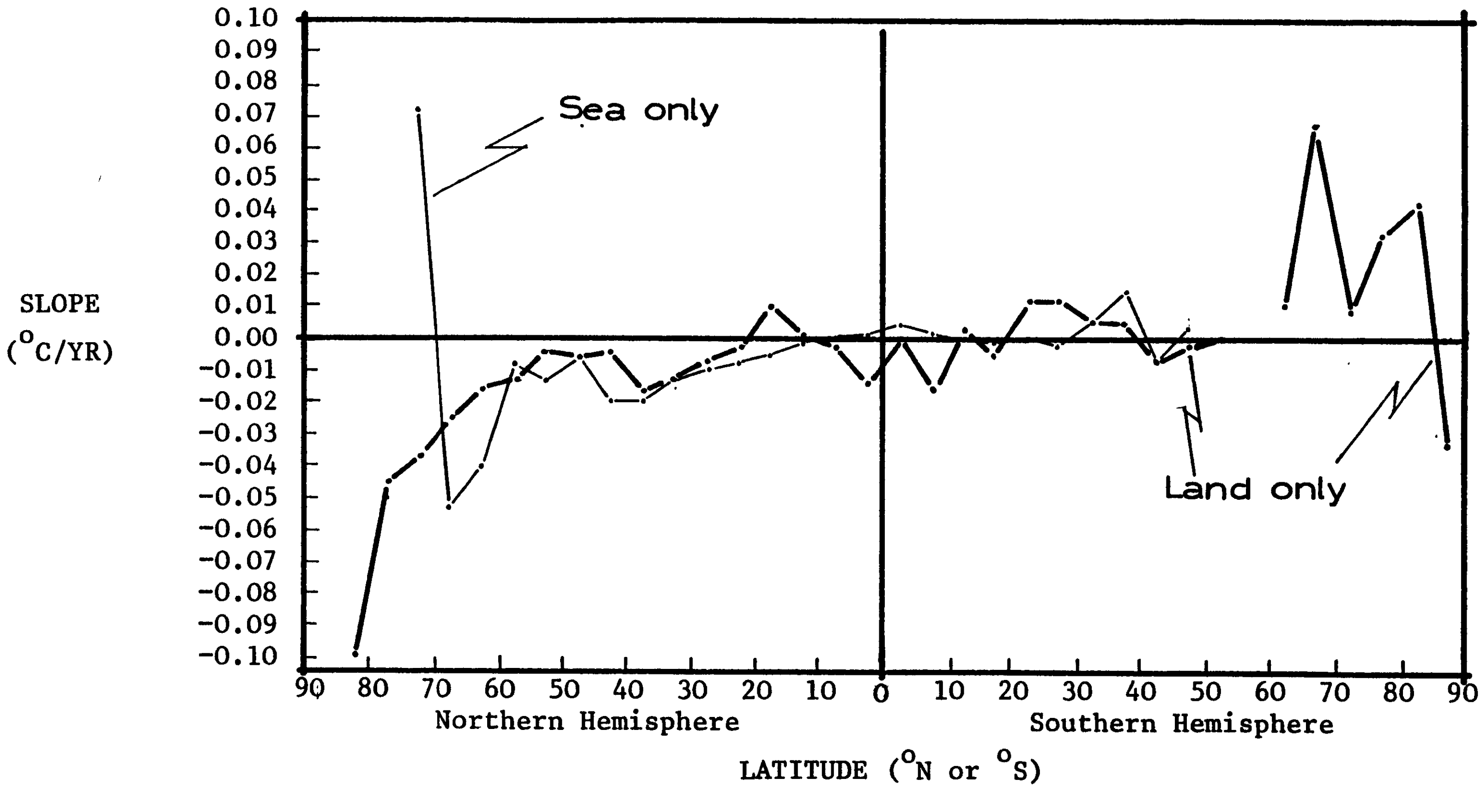
[a] less than ±0.0005.

[b] sea data not available during some or all years.

[c] test for auto-correlation ambiguous at the 95% confidence level.

[d] likely auto-correlation at the 95% confidence level.

Figure 11. Slopes of the Multi-Year Trend Lines for Land-Only and Sea-Only Annual Surface Air Temperature Anomalies As a Function of Latitude Band (°C/yr). Values are plotted at the mid-point of each 5°-wide latitude band.*



* Data at high latitudes based on less than 24 years of observations.

(1977, fig. 4) in winter. In general, the land-only and sea-only data yield qualitatively similar latitudinal distributions of trend (see Figure 11).

The latitudinal distribution of air temperature trends described above also matches well with the SST trends reported by Newell and Hsiung (1979). They noted significant cooling between the periods 1949-62 and 1963-72 north of 25-35°N in both the Atlantic and Pacific Oceans, with the largest trends north of 50°N. No significant trends were found in the tropics or the low latitudes of the Southern Hemisphere (to about 20-40°S) in the Atlantic, Pacific, or Indian Oceans. Their observed cooling trend in the Northern Hemisphere continues into the 1973-78 period, in agreement with Barnett's (1978) results.

The inhomogeneous nature of the temperature trends in the southern extra-tropics provides a possible explanation for the discrepancy noted in the previous chapter between the southern extra-tropical trends of Damon and Kunen (1976), Hansen *et al.* (1981), and this study and those of Angell and Korshover (1975, 1977, and 1978a) and Navato *et al.* (1981). Angell and Korshover selected six stations centered on the 40°S latitude circle for their south temperate zone (30°S - 60°S) and six located on the Antarctic continent for their south polar zone (60°S - 90°S). Figure 1 of Angell and Korshover (1977) illustrates that half of their south temperate stations are in the latitude bands between 40°S and 55°S which exhibit cooling in this study. Since their two zones were averaged together weighted by total area to form a regional mean for the entire southern extra-tropics (30°S - 90°S), any trend in the south temperate zone would tend to dominate this regional mean. Thus, the high cooling trend they report may be due to the influence of a few stations from a sub-region of apparent cooling, despite the more widespread warming found in this and other studies. Similarly, Navato *et al.* used 10 stations to generate a tropospheric temperature trend for the southern extra-tropics, half of which were from latitude bands that exhibit cooling in this study (40°S to 55°S and 85-90°S). However, they averaged their stations with equal weight and obtained a smaller cooling trend than Angell and Korshover.

Whether the above explanation is sufficient to account for all of the discrepancy in results will require more detailed analysis of the original station data to determine. Regardless, it is clear that extreme care is needed in developing an unbiased, geographically representative station network due to the highly regionalized nature of temperature trends (e.g., see Barnett, 1978, and van Loon and Williams, 1977). This is of special concern with respect to attempts to relate trends at a limited number of stations to hemispheric or global averages (e.g., Landsberg *et al.*, 1978; Groveman and Landsberg, 1979; Agee, 1980).

Comparison of Land, Sea, and Combined Land/Sea Trends

Figures 7-9 and Table VIIa illustrate the varying degree of similarity between land-only and sea-only curves for regions and the globe during 1949-72. Land-only trends are of the same sign as the sea-only trends in all cases, but appear generally greater in magnitude (by a few thousandths of a °C). Correlation coefficients are the highest in the tropics and the weakest in the southern extra-tropics. The strong

Table VII. Correlation Coefficients between Land-Only, Sea-Only, and Combined Land/Sea Annual Surface Air Temperature Anomalies for Regions and the Globe, 1949-72.

a) Land-Only versus Sea-Only Data

Region	No Lag	One-Year Lag: Land Leads	One-Year Lag: Sea Leads
Globe	0.707	0.353	-0.127
Northern Hemisphere	0.583	0.569	-0.071
Southern Hemisphere	0.495	0.037	0.065
Northern Extra-Tropics	0.483	0.503	0.245
Tropics	0.804	0.221	-0.179
Southern Extra-Tropics	0.079	-0.241	0.161

b) Combined Land/Sea versus Land-Only and Sea-Only Data

Region	Combined Land/Sea versus Land-Only	Combined Land/Sea versus Sea-Only	Land Area in Region (%)
Globe	0.806	0.825	29.5
Northern Hemisphere	0.901	0.816	39.3
Southern Hemisphere	0.461	0.721	19.7
Northern Extra-Tropics	0.909	0.708	46.6
Tropics	0.869	0.957	24.6
Southern Extra-Tropics	0.126	0.755	17.5

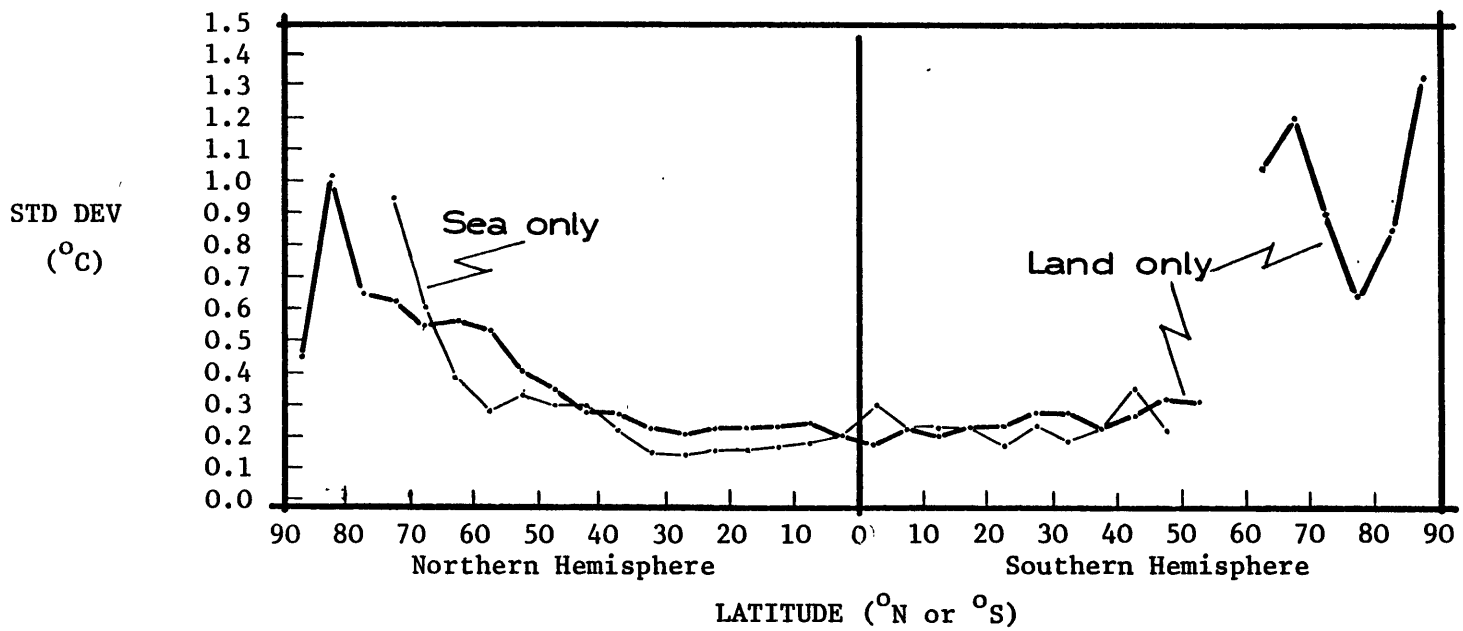
tropical correlations are consistent with the data of Bjerknes (1966), van Loon _et al._ (1972), Newell and Weare (1976), Navato _et al._ (1981), and others. However, some degree of correlation may be due to the prevalence of oceanic data near the coasts in this region as evident in Figures 3 and 4. The weak southern correlations may arise in part from the differing geographic coverage apparent in the southern extra-tropics (cf. Figures 1-2 and 3-4). Correlation coefficients with a one-year lag in either direction decrease in magnitude in most cases, although slight increases are apparent in the northern extra-tropics (with land leading) and in the southern extra-tropics (see the next chapter for a discussion of lags on monthly time scales).

In the southern extra-tropics (Figure 9c), the difference between the slopes of the land-only and sea-only curves is slightly larger than in other regions, some 0.008°C/yr. One possible explanation for this difference is that urban development and associated changes in local climatology may have subjected land-based thermometers to additional warming not representative of regional or global trends. Damon and Kunen (1976), for example, assumed that urban development caused the warming apparent in Southern Hemisphere stations located in cities of population greater than 750,000 over the period 1943-74 (see their Fig. 3; also, see Carter, 1978, and reply by Damon and Kunen, 1978). However, Figure 11 demonstrates that the land-only trends are not consistently greater than the sea-only trends throughout the southern extra-tropical latitudes (for which data exist). This suggests that more careful examination of the effect of urban development will be necessary, taking into account the potentially inhomogeneous nature of temperature trends. The possibility of biases in the sea-based data must also be considered.

Comparison of the interannual variability of the land-only and sea-only curves, as measured by the standard deviation, reveals some interesting characteristics. In the northern extra-tropics (Figure 9a), the standard deviation of the land-only curve is greater than that of the sea-only curve. However, the difference is less than the factor of 2-3 reported by Barnett (1978), who compared land-based SAT data with SST data, and by Parker (1981), who examined selected stations in high northern latitudes. In the tropics (Figure 9b), the reverse situation exists, i.e., the standard deviation of the sea-only curve slightly exceeds that of the land-only curve. This may be partly due to uneven sampling in the tropical Pacific Ocean, since data are sparse where variability is low and dense where variability is high according to SST data (Newell and Weare, 1976; Navato _et al._, 1981). In the southern extra-tropics, the land-only data appears slightly more variable than the sea-only data.

Examination of the standard deviations for the individual latitude bands (Figure 12) shows that the interannual variability over land is greatest near the poles, as pointed out by various authors (e.g., Mitchell, 1963; van Loon and Williams, 1976a). The distribution of variability bears an interesting resemblance to Figure 1 of Vinnikov and Groisman (1979), who developed an empirical model of the latitudinal distribution of climate change in relation to the northern extra-tropical

Figure 12. Standard Deviations of the Multi-Year Land-Only and Sea-Only Annual Surface Air Temperature Anomalies As a Function of Latitude Band (°C). Values are plotted at the mid-point of each 5°-wide latitude band.*



* Data at high latitudes based on less than 24 years of observations.

mean change based on Borzenkova et al.'s (1976) land-only data for 1881-1975. The air over the oceans evidences a similar pattern across latitudes for which data are available, consistent with the northern extratropical SST data of Barnett (1978). Taken together, these data provide strong empirical support for the hypothesis derived from climate models that the temperature sensitivity of the high latitudes may be relatively greater than that of low latitudes (e.g., Manabe and Wetherald, 1975; Schneider, 1975).

Also noteworthy in Figure 12 is the small peak in the standard deviations of the sea-only data at about 0-15°S, which corresponds to the highly variable SST trends for the Pacific Ocean reported by Newell and Hsiung. No significant changes in interannual variability are evident over the 24-year period.

Comparison of the land-only and sea-only curves with the combined land/sea curves illustrates the importance of using some objective method to merge the land-based and sea-based datasets. The global combined land/sea curve in Figure 7 has slightly smaller values of slope and standard deviation than both the land-only and sea-only curves.* This suggests that the air temperature of the earth as a whole is less "noisy" than might be construed from either the land-only or the sea-only curves alone. Indeed, the latter curves could, for example, reflect shifts in the mean positions of troughs and ridges of atmospheric circulation patterns, a possibility explored by Parker (1981). As in the case of regional trends, more detailed diagnostic studies of temperature patterns

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* This feature is not, however, evident in the regional curves (Figs. 8 and 9), although it is in some latitude bands (Table VII).

and their relation to dynamical processes such as performed by van Loon and Williams (1976a,b; 1977) and Williams and van Loon (1976) are likely to be necessary.

The comparisons of land, sea, and combined land/sea data in this section suggest the following three points:

1) The SAT data over the oceans collected by the U.K. Meteorological Office contain trend information that is both independent of and comparable in quality to that of the "traditional" WWR/MCDW land-based dataset. The striking consistency of sign, approximate magnitude, and standard deviation of sea-only and land-only trends for latitudes, regions, and the globe supports this contention. The sparsity of data from some ocean areas does not appear to be a serious problem in general. No clear indication of measurement biases due to urban development or thermometer movement is evident in the land-only data.

2) Land-only and sea-only curves alone are not fully representative of the behavior of a region or the earth as a whole. For example, correlation coefficients between the combined land/sea curve and the land-only and sea-only curves for the globe are only 0.806 and 0.825, respectively (see Table VIIb). Use of either of the latter curves as a surrogate for the combined land/sea curve would lead to overestimations of the global trend by 0.001-0.004°C (a factor of 50-300%) and the global standard deviation by 0.07-0.51°C. As noted earlier, this could be important with respect to attempts to detect global climate

changes. For regions, correlation coefficients drop as low as 0.126, reflecting differing proportions of land versus sea area and differing degrees of correlation between land-only and sea-only curves.

3) Any attempts to use observed temperature trends to validate models of climatic change should take into account possible real differences between trends over land and those over sea. Although artificial differences in land-only and sea-only trends could arise because of sampling errors, measurement biases, or other influences, there is certainly evidence to suggest that real differences may exist (e.g., Barnett, 1978; Parker, 1981; Bryan *et al.*, 1982). Indeed, the ability of a particular model to explain differences in observed land-based and sea-based trends could be an important test of its validity. Also of relevance is the high temperature sensitivity of the air over the oceans in the Northern Hemisphere.

V. MONTHLY TEMPERATURE TRENDS

The global time series of monthly temperature anomalies for combined land/sea, land-only, and sea-only data are depicted in Figure 13 and tabulated along with the regional time series in Appendix B. Standard deviations for each set of 288 monthly values (January 1949 to December 1972) for regions and the globe are presented in Table VIII. Correlations and auto-correlations for land and sea data are given in Table IX.*

The monthly time series of this study and Jones *et al.* (1981) appear in close agreement (Figure 14). The correlation coefficient between their monthly land-only curve for the Northern Hemisphere and that of this study is 0.896, a relatively small decrease from the correlation on annual time scales (0.970) given the order-of-magnitude increase in degrees of freedom. The standard deviation of their curve is 0.300, slightly smaller than the value of 0.378 reported in Table VIII. This lower monthly (non-seasonal) variability could be due to their use of a limited base period (1946-60) in the formation of station anomalies, if the magnitude of the seasonal temperature cycle were generally greater during this period than during 1949-72. In any case, the differing monthly variability appears to have negligible effect at annual time scales, since as noted in the previous chapter annual time series formed directly from the monthly time series of both studies are in close agreement.

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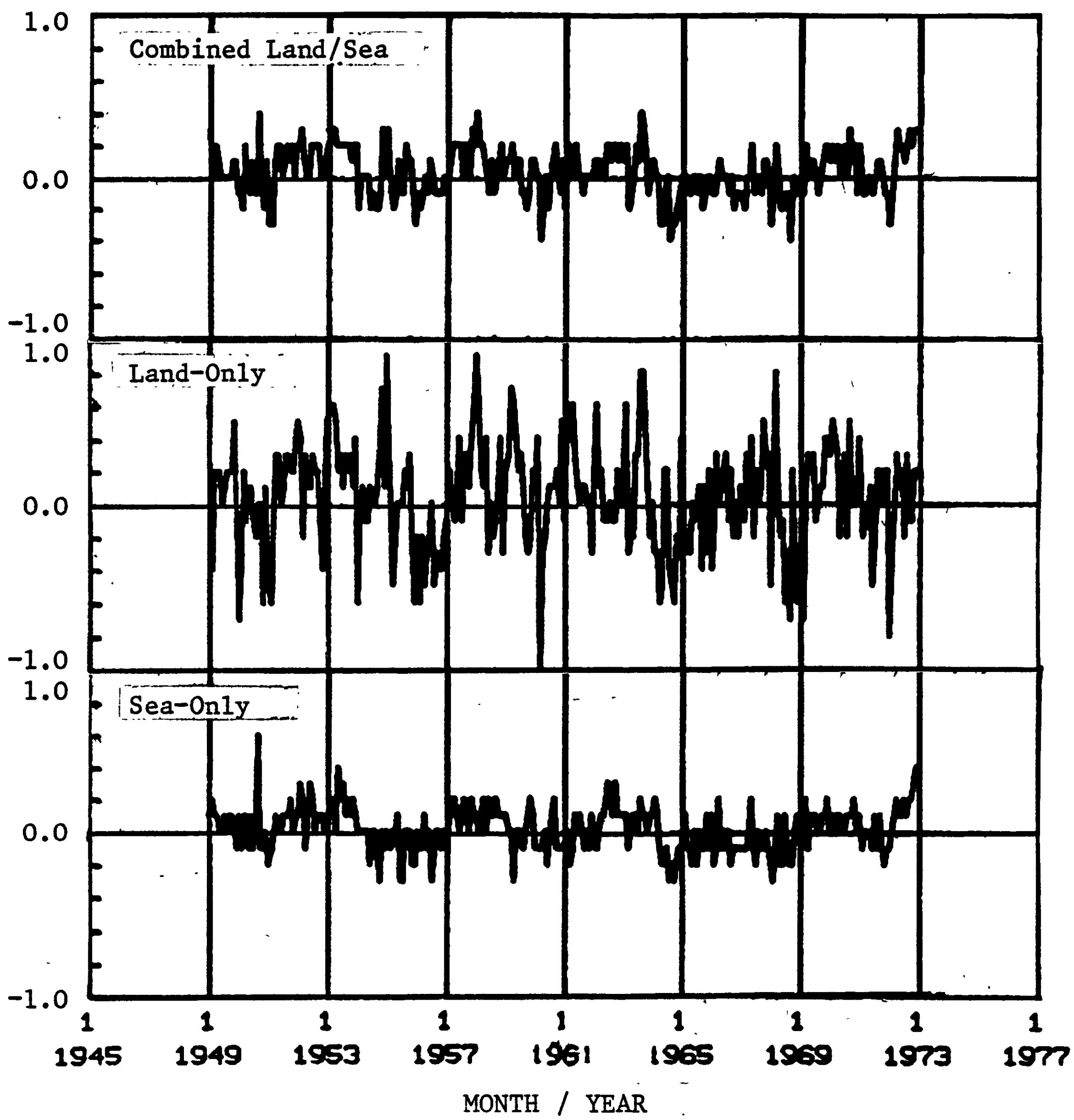
* Regression statistics are not presented due to the presence of significant auto-correlation in most curves.

Figure 13. Monthly Surface Air Temperature Anomalies for the Globe, January 1949 to December 1972 (^{o}C).*



* See Tables IX and X for associated statistics.

Table VIII. Standard Deviations of Monthly Surface Air Temperature Anomalies for Regions and the Globe, January 1949 to December 1972 (^{o}C).

Region	Combined Land/Sea Data	Land-Only Data	Sea-Only Data*
Globe	0.154	0.321	0.137
Northern Hemisphere	0.210	0.378	0.172
Southern Hemisphere	0.229	0.529	0.195
Northern Extra-Tropics	0.278	0.478	0.215
Tropics	0.216	0.260	0.219
Southern Extra-Tropics	0.350	0.863	0.297

* Missing month December 1962 was interpolated.

Table IX. Correlation and Auto-Correlation Coefficients for Land-Only and Sea-Only Monthly Surface Air Temperature Anomalies for Regions and the Globe, July 1949 to December 1972.*

a) Correlations between Land-Only and Sea-Only Data.

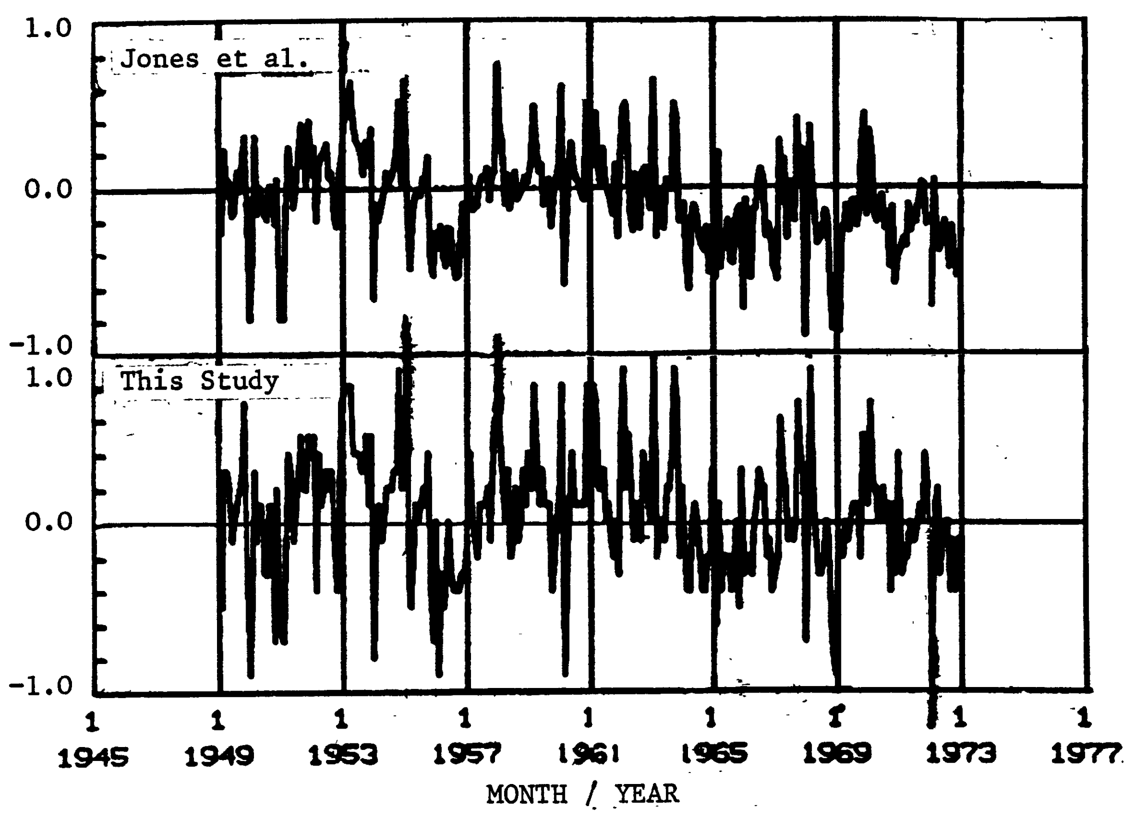
Region	No Lag	Land Leads by 1 mo.	Land Leads by 2 mos.	Sea Leads by 1 mo.	Sea Leads by 2 mos.
Globe	0.172	0.191	0.169	0.188	0.141
Northern Hemisphere	0.178	0.216	0.214	0.229	0.146
Southern Hemisphere	0.125	0.062	0.075	0.182	0.117
Northern Extra-Tropics	0.105	0.127	0.119	0.140	0.077
Tropics	0.704	0.706	0.703	0.645	0.582
Southern Extra-Tropics	0.009	0.014	-0.011	0.116	0.049

b) Auto-Correlation Coefficients (One-Month Lag)

Region	Land-Only Data	Sea-Only Data
Globe	0.372	0.415
Northern Hemisphere	0.381	0.615
Southern Hemisphere	0.228	0.246
Northern Extra-Tropics	0.363	0.387
Tropics	0.701	0.879
Southern Extra-Tropics	0.168	0.232

* Restricted range due to use of lagged variables (one- to six-months). In sea-only data, the missing month December 1962 was interpolated.

Figure 14. Comparison of Northern Hemisphere, Land-Only Monthly Surface Air Temperature Anomalies of This Study and Jones et al. (1981), January 1949 to December 1972 (^{o}C).*



* See Tables IX and X and text for statistics.

Comparison of Land and Sea Data

Table VIII illustrates that the monthly variability of the land-only curves is consistently greater than that of the sea-only curves for regions and the globe. Outside of the tropics, the variability differs by at least a factor of two, a much greater difference than evident at interannual time scales. The difference is most likely due to the greater heat capacity of the oceans, which would tend to smooth out temperature fluctuations on monthly and seasonal time scales. This contention is supported by the consistently higher auto-correlations in the sea-only data evident in Table IXb. In the tropics, the monthly standard deviations over land and sea are of the same magnitude and indeed are only slightly greater than the annual values reported in Figure 9b.

As with the annual data, the monthly standard deviations increase toward the poles, although the increase is generally greater in the land-only data than in the sea-only data (see Table X). This land/sea difference could be due to different latitudinal distributions of heat capacity of land and sea (Schneider and Thompson, 1981; Bryan *et al.*, 1982). A small relative rise in the standard deviation of the sea-only data is evident from 5°S to 5°N, probably corresponding to the high variability in the Pacific Ocean reported by Newell and Hsiung (1979).

Correlations between the land-only and sea-only data are not generally high except in the tropics (Table IXa). Indeed, the high coefficient in the latter region may be partly due to the correlation on interannual time scales, since as noted above the monthly fluctuations do not

Table X. Standard Deviations of Monthly Surface Air Temperature Anomalies for Latitude Bands, January 1949 to December 1972 (°C).

Latitude Band	Combined Land/Sea Data	Land-Only Data	Sea-Only Data**
85-90°N	0.312*	0.312*	NA
80-85°N	2.982*	2.982*	NA
75-80°N	1.534	1.533	1.722*
70-75°N	1.349	1.462	1.733*
65-70°N	1.135	1.291	1.518*
60-65°N	0.973	1.279	0.977*
55-60°N	0.807	1.362	0.580
50-55°N	0.695	1.049	0.574
45-50°N	0.619	0.973	0.514
40-45°N	0.461	0.729	0.535
35-40°N	0.371	0.582	0.437
30-35°N	0.281	0.454	0.341
25-30°N	0.274	0.459	0.285
20-25°N	0.257	0.417	0.265
15-20°N	0.273	0.470	0.260
10-15°N	0.250	0.457	0.241
5-10°N	0.255	0.348	0.257
0- 5°N	0.292	0.323	0.317
0- 5°S	0.304	0.273	0.340
5-10°S	0.265	0.299	0.284
10-15°S	0.230	0.333	0.254
15-20°S	0.233	0.377	0.250
20-25°S	0.253	0.412	0.289
25-30°S	0.304	0.564	0.350
30-35°S	0.290	0.566	0.321
35-40°S	0.377	0.627	0.392
40-45°S	0.538	0.689	0.557
45-50°S	1.209	0.966	1.256*
50-55°S	0.872	0.732	0.938*
55-60°S	0.977*	NA	0.977*
60-65°S	1.876*	1.838*	1.264*
65-70°S	2.028*	2.093*	0.793*
70-75°S	2.202*	2.324*	0.828*
75-80°S	4.502*	4.518*	1.840*
80-85°S	3.058*	3.058*	NA
85-90°S	4.473*	4.473*	NA

* not all months available.
** December 1962 omitted.

dominate the overall variability as in other regions. Correlations with one- to six-month lags in either direction (only coefficients for one- to two-month lags are listed) show no substantial increases except in the southern extra-tropics when the sea-only data leads the land-only data by one month. However, an increase of this kind is not evident in any land/sea correlations for individual latitude bands (not shown) in this region.

The correlations between the monthly land-only and sea-only curves could be low for several different reasons, for example:

1) Excessive noise in the sea-only data. This might be due, for instance, to the low number of observations per month in some areas, time-varying geographic coverage (see Figure 6), or insufficient instrument accuracy to capture monthly fluctuations.

2) Excessive noise in the land-only data. The high monthly variability of the land-only curves (e.g., Figure 13b) could reflect local climatological influences, measurement inaccuracies, or other problems.

3) Real differences in temperature behavior on monthly time scales. Such differences could arise from the differing heat capacities of land and ocean (as already mentioned), the influence of topography on land-based measurements, or other dynamical factors (e.g., the presence of ocean currents or upwelling and differing distributions of wind or clouds).

Clearly, more detailed analyses of the monthly data will be necessary to determine which of the above reasons (or perhaps another) contribute to the low monthly correlations. Of particular interest would be comparisons with monthly time series of SST's, since these should be thermodynamically related to SAT's (e.g., Navato *et al.*; Barnett, 1978).

VI. SUMMARY AND CONCLUSIONS

The instrumental record of the earth's surface temperature is extremely limited in both time and space. Relatively few measurement stations have existed for more than a century and even present stations are widely and irregularly spaced. A major difficulty is the sparsity of long-term observations in oceanic areas and the Southern Hemisphere, which together constitute some 80% of the surface area of the earth.

This situation is of particular concern for a variety of reasons, including:

1) The earth's climate can vary greatly over short periods of time and short distances, so that the present observational network may not be adequate to indicate the full extent of regional or global fluctuations.
2) Small shifts in atmospheric circulation patterns, regional variations, or internal redistributions of energy between components of the climate system (e.g., atmosphere, oceans, and ice) could be misinterpreted as global climate changes and could perhaps be attributed incorrectly to external factors.
3) The possibility exists that measurement biases or local climatological influences such as the "heat island" effect of urban development and the movement of stations to airports could have been sufficiently common to have produced artificial temperature trends in regional and global datasets.

4) Models of climate and climatic change usually treat the surface air temperature as a parameter that is inherently hemispheric or global and is not subject to the same sampling problems and data limitations as observed temperature trends (Schneider and Mass, 1975).

Despite these caveats, the earth's surface temperature is still one of the most (if not the most) comprehensively and consistently measured features of the earth's climate -- and also one of considerable direct importance to human activities. Thus, it is not surprising that there have been over 25 different published studies of observed hemispheric or global temperature trends and many more papers on the mechanism and causes of temperature fluctuations on a variety of time and space scales. However, none of these studies have been able to deal adequately with the limitations described above.

This study is an initial attempt to characterize the earth's temperature behavior more fully using worldwide surface air temperature measurements from both land and ocean areas. A unique collection of ship-based SAT observations prepared by the U.K. Meteorological Office was analyzed in parallel with the station-based dataset developed by the National Center for Atmospheric Research from the publications World Weather Records and Monthly Climatic Data for the World. Together, these datasets provide coverage of up to 81% of the surface area of the globe. Although limited to an admittedly short 24-year period, the analysis reveals some features of the climate that are certainly important to consider in any period of time.

The principal findings of this exploratory study are worth summarizing briefly:

1) Hemispheric and global temperature trends may not be very sensitive to specific data-processing techniques, since the results of this study agree well with those of other studies, most notably the monthly and annual analyses of Jones *et al.* (1981) for the Northern Hemisphere and the annual analysis of Vinnikov *et al.* (1980) for the northern extra-tropics. However, care is needed in formulating trends to ensure balanced representation of all areas of the globe and accurate estimation of noise levels (i.e., standard deviations) for detection purposes.
2) The earth as a whole experienced no significant trend over the period 1949-72, despite statistically significant but opposing trends in the northern and southern extra-tropics.
3) Temperature trends are not necessarily homogeneous either between or within regions, which underscores the need noted by other analysts for reasonably dense and regular temperature observations worldwide.
4) Both land and ocean areas at high latitudes exhibit high variability on both monthly and interannual time scales, consistent with other empirical and climate-model studies. On monthly time scales, the pattern of variability differ somewhat, in a way that may be associated with the differing heat capacities of land and oceans.

5) The sea-based (UK) dataset provides a here-to-fore unutilized indicator of the earth's temperature behavior that is independent of the land-based (WWR/MCDW) dataset and is comparable in information quality.

6) Air temperatures over land and sea exhibited qualitatively similar interannual trends over the period 1949-72, although slight differences of uncertain origin are apparent that demonstrate the need for data from both land and sea areas. No differences between interannual land and sea trends are evident that can be clearly attributed to the effects of local influences or instrument biases on land-based station measurements.

It should be clear from the above list that this study raises (or revives) many more questions than it answers. For example,

-- Is the lack of trend for the earth as a whole during the period 1949-72 a change from or a continuation of prior trends -- i.e., is the apparent Northern Hemisphere warming trend from the 1880's to the 1940's a regional or global phenomenon?

-- Are the opposing northern and southern extra-tropical trends coincidental or, if not, due to either internal or external mechanisms -- or both (e.g., Robock, 1978)?

-- What are the primary determinants of the distribution of temperature trends by region and latitude? Can such a distribution be expected to apply to future climatic changes if they should occur?

-- What mechanisms are responsible for the differing degree of correlation between land-based and sea-based temperature trends in different regions, on both monthly and inter-annual time scales? To what extent and in what ways are sea surface temperatures related?

-- Does the combined land/sea dataset include sufficient spatial and temporal coverage to provide reliable global estimates of natural climatic variability and possible long-term climatic changes?

To answer such questions as these will require much more extensive study than was possible here, not only of temperature data but also of related atmospheric and oceanic parameters. In particular, the sea-based dataset used in this study creates new opportunities for diagnostic studies of atmospheric circulation and temperature (e.g., van Loon and Williams, 1976a,b, 1977, 1978; Williams and van Loon, 1976), for applications of spatial analysis techniques such as empirical orthogonal functions (e.g., Barnett, 1978; Newell and Weare, 1976; Weare et al., 1976), and for other empirical analyses (e.g., Vinnikov and Groisman, 1977). Of special interest is the much greater coverage of the Southern Hemisphere that the dataset provides, which should permit extension of the above-mentioned approaches to this region.

The review and analyses presented in this paper clearly suggest that much further work will be needed to develop a truly comprehensive picture of the earth's temperature behavior. A major priority should be to extend the sea-based dataset and associated analyses beyond the period 1949-72, as is currently being undertaken at the U.K. Meteorological Office and the Massachusetts Institute of Technology (Newell, personal communication, 1981). Such work will be essential to any attempts to test hypotheses about the mechanisms and causes of climatic fluctations or change (e.g., Budyko, 1969, 1977; Mitchell, 1970; Schneider and Mass, 1975; Miles and Gildersleeves, 1977; Hoyt, 1979; Agee, 1980; Hansen _et al._, 1981) and to detect possible long-term climatic changes (e.g., Madden and Ramanathan, 1980; Wigley and Jones, 1981). This study is offered both as an interim review of the work of the past three decades to develop hemispheric or global temperature trends, with special attention to possible gaps and limitations, and as an exploratory analysis that will hopefully spur much-needed further efforts in the near future.

APPENDIX A -- Annual Surface Air Temperature Anomalies, 1949-72, for Regions and the Globe.

Table A-1. Annual Surface Air Temperature Anomalies for the Globe, 1949-72 ($^{o}C \times 10$).

Combined Land/Sea Data

1949	1.	-1.	0.	1.	2.	-1.
1955	0.	-1.	1.	1.	0.	0.
1961	1.	1.	1.	-1.	-1.	-1.
1967	0.	-2.	1.	1.	0.	0.

Land-Only Data

1949	2.	-1.	1.	1.	3.	1.
1955	0.	-3.	1.	2.	2.	0.
1961	2.	1.	2.	-2.	-1.	0.
1967	1.	-2.	1.	1.	0.	-1.

Sea-Only Data

1949	1.	0.	0.	1.	2.	-1
1955	-1.	-2.	1.	1.	0.	0.
1961	0.	1.	1.	-1.	-1.	0.
1967	-1.	-2.	1.	0.	-1.	1.

Table A-2. Annual Surface Air Temperature Anomalies for the Hemispheres, 1949-72. (°C x 10).

a) Northern Hemisphere

Combined Land/Sea Data

1949	2.	-1.	1.	2.	4.	1.
1955	0.	-2.	0.	2.	1.	1.
1961	1.	2.	1.	-1.	-1.	0.
1967	0.	-2.	0.	0.	-1.	-1.

Land-Only Data

1949	2.	-1.	1.	1.	5.	1.
1955	0.	-3.	1.	2.	2.	2.
1961	2.	2.	2.	-2.	-2.	-1.
1967	1.	-2.	-1.	1.	0.	-3.

Sea-Only Data

1949	1.	-1.	1.	2.	2.	-1.
1955	-1.	-2.	0.	1.	0.	0.
1961	0.	1.	0.	0.	-1.	0.
1967	-1.	-2.	1.	0.	-2.	0.

Table A-2 (continued)

b) Southern Hemisphere

Combined Land/Sea Data

1949	0.	-1.	-1.	1.	0.	-2.
1955	0.	1.	2.	1.	-1.	-1.
1961	0.	1.	1.	-2.	0.	-1.
1967	0.	-1.	1.	2.	0.	2.

Land-Only Data

1949	1.	-1.	1.	1.	0.	-1.
1955	-1.	-2.	2.	2.	2.	-2.
1961	2.	-2.	0.	-2.	0.	1.
1967	1.	-2.	4.	3.	0.	1.

Sea-Only Data

1949	0.	0.	-1.	0.	1.	-1.
1955	-2.	-1.	1.	2.	0.	-1.
1961	0.	1.	2.	-2.	0.	-1.
1967	-1.	-1.	1.	1.	0.	2.

Table A-3. Annual Surface Air Temperature Anomalies for the Tropical/ Extra-Tropical Regions, 1949-72 (^{o}C x 10).

a) Northern Extra-Tropics

Combined Land/Sea Data

1949	2.	0.	1.	2.	5.	2.
1955	0.	-2.	0.	1.	1.	1.
1961	1.	2.	0.	-1.	-2.	-1.
1967	1.	-2.	-1.	-1.	0.	-2.

Land-Only Data

1949	2.	-1.	1.	1.	6.	2.
1955	1.	-4.	1.	2.	2.	2.
1961	3.	3.	2.	-2.	-2.	-1.
1967	2.	-2.	-2.	0.	0.	-4.

Sea-Only Data

1949	2.	0.	1.	3.	2.	0.
1955	0.	-1.	-1.	0.	0.	1.
1961	1.	1.	-2.	1.	-1.	-1.
1967	0.	-2.	-1.	-1.	-1.	0.

Table A-3 (continued)

b) Tropics

Combined Land/Sea Data

1949	1.	-2.	1.	2.	2.	-2.
1955	-3.	-3.	1.	3.	1.	0.
1961	-1.	0.	1.	-1.	0.	1.
1967	-2.	-1.	3.	0.	-3.	3.

Land-Only Data

1949	2.	-2.	1.	2.	2.	0.
1955	-1.	-2.	1.	3.	2.	1.
1961	-1.	-1.	0.	-1.	-1.	1.
1967	-2.	-2.	3.	2.	-2.	2.

Sea-Only Data

1949	1.	-1.	1.	2.	2.	-2.
1955	-3.	-4.	1.	2.	1.	0.
1961	0.	0.	2.	-1.	0.	0.
1967	-2.	-1.	3.	0.	-3.	2.

Table A-3 (continued)

c) Southern Extra-Tropics

Combined Land/Sea Data

1949	-2.	0.	-2.	0.	-1.	-2.
1955	1.	3.	1.	-1.	-1.	-1.
1961	1.	3.	1.	-2.	0.	-1.
1967	1.	-1.	0.	3.	2.	1.

Land-Only Data

1949	1.	1.	0.	0.	-3.	-2.
1955	-2.	-3.	3.	0.	2.	-3.
1961	4.	-3.	1.	-2.	1.	2.
1967	3.	-1.	5.	3.	1.	1.

Sea-Only Data

1949	-1.	2.	-3.	-1.	0.	0.
1955	1.	1.	0.	1.	0.	-2.
1961	0.	3.	1.	-2.	-1.	-2.
1967	1.	-2.	0.	2.	2.	1.

APPENDIX B -- Monthly Surface Air Temperature Anomalies, January 1949 to December 1972, for Regions and the Globe.

Table B-1. Monthly Surface Air Temperature Anomalies for the Globe, January 1949 to December 1972 (^{o}C x 10).

Combined Land/Sea Data

1949	1	3.	0.	2.	1.	0.	0.
1949	7	0.	0.	0.	1.	1.	-1.
1950	1	-1.	-2.	2.	0.	-1.	1.
1950	7	-1.	-1.	4.	-1.	-2.	1.
1951	1	-3.	-3.	1.	2.	2.	0.
1951	7	1.	2.	1.	2.	0.	2.
1952	1	2.	3.	1.	0.	0.	2.
1952	7	2.	2.	2.	0.	0.	1.
1953	1	2.	3.	3.	2.	2.	2.
1953	7	2.	2.	2.	1.	2.	2.
1954	1	-2.	0.	0.	0.	0.	-2.
1954	7	-1.	-2.	-2.	-1.	3.	0.
1955	1	3.	-1.	-2.	-1.	1.	-1.
1955	7	-1.	2.	1.	1.	-1.	-3.
1956	1	-1.	-2.	-1.	0.	-1.	1.
1956	7	0.	-1.	-1.	-1.	-1.	0.
1957	1	-1.	1.	2.	2.	2.	2.
1957	7	0.	2.	2.	0.	3.	2.
1958	1	4.	2.	2.	1.	0.	-1.
1958	7	1.	-1.	0.	1.	2.	0.
1959	1	1.	1.	2.	0.	1.	1.
1959	7	-1.	-1.	-2.	-1.	1.	1.
1960	1	0.	0.	-4.	-2.	0.	-2.
1960	7	0.	1.	2.	0.	-1.	1.
1961	1	-2.	2.	0.	1.	2.	0.
1961	7	0.	-1.	0.	0.	0.	0.
1962	1	1.	1.	0.	1.	0.	2.
1962	7	2.	1.	2.	2.	1.	2.
1963	1	1.	2.	-2.	-1.	0.	2.
1963	7	1.	4.	3.	1.	-1.	0.
1964	1	1.	0.	0.	-3.	-3.	-1.
1964	7	0.	-4.	-3.	-3.	-2.	-1.
1965	1	0.	0.	-1.	-1.	0.	0.
1965	7	-1.	0.	-2.	-1.	0.	0.
1966	1	-1.	-1.	0.	1.	0.	0.
1966	7	0.	-1.	0.	-2.	-1.	-1.
1967	1	-1.	-2.	0.	0.	2.	-1.
1967	7	0.	0.	-1.	1.	1.	0.
1968	1	-3.	-1.	2.	0.	-2.	-2.
1968	7	-1.	-1.	-4.	0.	-1.	-1.
1969	1	0.	-1.	2.	0.	1.	1.
1969	7	0.	-1.	0.	1.	2.	2.
1970	1	1.	2.	1.	2.	0.	0.
1970	7	2.	0.	3.	1.	2.	-1.
1971	1	2.	-1.	-1.	0.	0.	-1.
1971	7	0.	1.	1.	0.	-1.	-1.
1972	1	-3.	-1.	1.	3.	2.	2.
1972	7	1.	2.	3.	2.	3.	3.

Table B-1 (continued)

Land-Only Data

1949	1	6.	-4.	2.	2.	2.	0.
1949	7	1.	2.	2.	2.	5.	-1.
1950	1	-7.	-3.	2.	-1.	1.	1.
1950	7	-1.	-2.	0.	0.	-6.	1.
1951	1	-5.	-6.	0.	3.	3.	0.
1951	7	1.	3.	3.	2.	2.	4.
1952	1	5.	4.	-2.	3.	1.	1.
1952	7	3.	2.	2.	-1.	-4.	1.
1953	1	5.	6.	6.	5.	2.	3.
1953	7	1.	3.	2.	3.	1.	4.
1954	1	-6.	0.	1.	-1.	-1.	1.
1954	7	0.	0.	1.	3.	7.	1.
1955	1	9.	0.	-5.	-2.	0.	0.
1955	7	0.	2.	1.	3.	-3.	-6.
1956	1	-2.	-6.	-2.	-5.	-3.	-2.
1956	7	0.	-5.	-3.	-4.	-4.	-2.
1957	1	-1.	2.	0.	-1.	1.	4.
1957	7	-1.	3.	3.	1.	4.	6.
1958	1	9.	6.	2.	1.	4.	-3.
1958	7	0.	-2.	-1.	1.	4.	-3.
1959	1	2.	3.	7.	6.	4.	2.
1959	7	3.	1.	-2.	-3.	-2.	2.
1960	1	1.	4.	-10.	-3.	-2.	0.
1960	7	1.	1.	1.	2.	0.	5.
1961	1	-1.	6.	4.	6.	3.	1.
1961	7	0.	1.	1.	0.	0.	-3.
1962	1	2.	6.	1.	2.	-1.	-1.
1962	7	-1.	0.	-1.	-1.	2.	1.
1963	1	0.	6.	-3.	-2.	-2.	3.
1963	7	3.	8.	8.	5.	1.	-2.
1964	1	0.	-3.	-3.	-6.	-5.	2.
1964	7	2.	-4.	-5.	-6.	-2.	-3.
1965	1	4.	-3.	-2.	-3.	0.	-1.
1965	7	0.	1.	-4.	1.	-3.	2.
1966	1	-4.	-1.	3.	0.	1.	2.
1966	7	3.	-1.	2.	-2.	0.	-2.
1967	1	1.	-1.	3.	0.	4.	-2.
1967	7	2.	0.	1.	5.	3.	3.
1968	1	-5.	2.	8.	0.	-2.	-1.
1968	7	-6.	-3.	-7.	2.	-3.	-6.
1969	1	-4.	-7.	1.	3.	2.	3.
1969	7	-1.	0.	1.	1.	4.	4.
1970	1	3.	5.	4.	3.	-2.	2.
1970	7	3.	-2.	5.	0.	1.	0.
1971	1	4.	-2.	-1.	-1.	1.	-5.
1971	7	-2.	2.	2.	0.	2.	2.
1972	1	-8.	-3.	0.	3.	1.	2.
1972	7	-2.	3.	-1.	-1.	2.	2.

Table B-1 (continued)

Sea-Only Data

1949 1	1.	2.	1.	1.	0.	0.
1949 7	1.	0.	1.	1.	0.	-1.
1950 1	1.	-1.	1.	1.	-1.	1.
1950 7	-1.	1.	6.	-1.	-1.	0.
1951 1	-2.	-1.	0.	1.	0.	0.
1951 7	1.	1.	1.	2.	0.	1.
1952 1	1.	3.	2.	-1.	1.	3.
1952 7	2.	0.	1.	1.	1.	0.
1953 1	1.	1.	2.	0.	4.	2.
1953 7	3.	1.	2.	1.	2.	1.
1954 1	0.	0.	0.	0.	0.	-2.
1954 7	0.	0.	-1.	-3.	0.	-1.
1955 1	0.	-1.	0.	0.	1.	-3.
1955 7	-3.	0.	0.	0.	-2.	-2.
1956 1	0.	-1.	-1.	1.	-1.	0.
1956 7	-3.	-1.	0.	0.	-1.	0.
1957 1	-1.	1.	2.	2.	1.	0.
1957 7	1.	2.	1.	0.	2.	1.
1958 1	1.	0.	1.	2.	0.	2.
1958 7	1.	1.	2.	1.	1.	1.
1959 1	1.	0.	0.	-3.	0.	0.
1959 7	0.	-1.	0.	1.	2.	1.
1960 1	-1.	-1.	-1.	-1.	0.	-2.
1960 7	0.	1.	2.	-1.	-1.	-1.
1961 1	-1.	0.	-2.	-1.	1.	0.
1961 7	1.	0.	-1.	0.	-1.	1.
1962 1	0.	-1.	0.	1.	1.	2.
1962 7	3.	2.	1.	3.	1.	NA
1963 1	1.	1.	-1.	0.	1.	1.
1963 7	0.	2.	1.	1.	0.	1.
1964 1	1.	2.	1.	-1.	-2.	-2.
1964 7	-1.	-3.	-2.	-3.	-2.	-1.
1965 1	-1.	1.	-1.	-1.	-2.	0.
1965 7	-2.	0.	-1.	-1.	1.	-1.
1966 1	1.	-2.	-1.	2.	-1.	0.
1966 7	-1.	0.	-2.	-1.	-1.	-1.
1967 1	-1.	-1.	-1.	0.	2.	-1.
1967 7	-2.	0.	-1.	-1.	0.	-1.
1968 1	-2.	-3.	-1.	1.	-2.	-2.
1968 7	1.	-1.	-2.	-2.	0.	1.
1969 1	1.	1.	2.	-1.	1.	1.
1969 7	1.	0.	0.	1.	1.	2.
1970 1	0.	1.	0.	1.	1.	0.
1970 7	0.	1.	1.	1.	2.	0.
1971 1	1.	-1.	0.	0.	0.	-1.
1971 7	1.	-1.	1.	-1.	-2.	-1.
1972 1	-1.	0.	1.	2.	1.	1.
1972 7	2.	1.	2.	2.	3.	4.

Table B-2. Monthly Surface Air Temperature Anomalies for the Hemispheres, January 1949 to December 1972 ($^{o}C \times 10$).

a) Northern Hemisphere

Combined Land/Sea Data

1949	1	4.	-1.	3.	3.	2.	0.
1949	7	0.	1.	2.	2.	3.	-2.
1950	1	-5.	-3.	2.	-1.	1.	1.
1950	7	-1.	-1.	0.	0.	-3.	1.
1951	1	-3.	-4.	-1.	3.	2.	1.
1951	7	2.	3.	4.	3.	1.	3.
1952	1	2.	5.	-1.	3.	3.	2.
1952	7	3.	2.	3.	1.	0.	1.
1953	1	4.	5.	6.	7.	5.	3.
1953	7	4.	3.	2.	2.	4.	4.
1954	1	-2.	0.	0.	1.	1.	1.
1954	7	0.	0.	1.	0.	4.	0.
1955	1	5.	-1.	-2.	-2.	0.	-1.
1955	7	-2.	0.	1.	2.	-1.	-5.
1956	1	0.	-3.	-2.	-2.	-3.	-1.
1956	7	-2.	-3.	-4.	-3.	-1.	0.
1957	1	-2.	2.	0.	-1.	-1.	1.
1957	7	2.	2.	2.	1.	4.	2.
1958	1	6.	2.	3.	1.	2.	1.
1958	7	0.	2.	1.	0.	2.	1.
1959	1	1.	2.	3.	0.	0.	1.
1959	7	0.	0.	0.	-1.	2.	1.
1960	1	2.	3.	-4.	-1.	2.	2.
1960	7	1.	1.	1	0.	2.	3.
1961	1	0.	3.	3.	1.	1.	1.
1961	7	0.	0.	-1.	-1.	0.	-2.
1962	1	2.	5.	1.	2.	0.	-1.
1962	7	1.	0.	0.	3.	2.	2.
1963	1	1.	3.	-1.	0.	0.	0.
1963	7	1.	3.	2.	4.	2.	0.
1964	1	2.	2.	-1.	-2.	-1.	0.
1964	7	-1.	-3.	-3.	-3.	-3.	-2.
1965	1	0.	-2.	-1.	-3.	-2.	-2.
1965	7	-3.	-3.	-2.	0.	-1.	1.
1966	1	-2.	-1.	-1.	-2.	-1.	0.
1966	7	1.	0.	0.	-1.	-2.	-1.
1967	1	-2.	-2.	1.	0.	2.	-1.
1967	7	0.	-1.	0.	1.	0.	0.
1968	1	-5.	-2.	2.	0.	-2.	-1.
1968	7	-1.	-1.	-2.	-2.	-4.	-3.
1969	1	-3.	-4.	0.	1.	1.	1.
1969	7	1.	1.	1.	-1.	1.	3.
1970	1	1.	2.	1.	1.	0.	0.
1970	7	-1.	0.	0.	-1.	-1.	-2.
1971	1	0.	-2.	-2.	-1.	0.	-2.
1971	7	-1.	-1.	0.	-1.	-1.	0.
1972	1	-5.	-2.	1.	0.	-2.	0.
1972	7	1.	0.	-1.	0.	-1.	0.

Table B-2 (continued)

a) Northern Hemisphere (continued)

Land-Only Data

1949	1	6.	-5.	3.	3.	2.	-1.
1949	7	0.	1.	2.	3.	7.	-3.
1950	1	-9.	-4.	3.	-1.	1.	1.
1950	7	-3.	-3.	1.	1.	-7.	2.
1951	1	-6.	-7.	-1.	4.	3.	-1.
1951	7	1.	3.	5.	2.	2.	5.
1952	1	4.	5.	-4.	4.	1.	2.
1952	7	3.	2.	3.	-1.	-4.	1.
1953	1	7.	8.	8.	8.	4.	4.
1953	7	4.	3.	3.	5.	1.	5.
1954	1	-8.	0.	1.	-1.	0.	2.
1954	7	2.	2.	3.	3.	9.	2.
1955	1	12.	0.	-5.	-2.	1.	0.
1955	7	1.	2.	1.	4.	-4.	-7.
1956	1	0.	-9.	-3.	-5.	-3.	0.
1956	7	-3.	-4.	-4.	-4.	-3.	-3.
1957	1	-2.	4.	0.	-1.	-2.	1.
1957	7	1.	1.	2.	-1.	3.	6.
1958	1	11.	5.	2.	0.	3.	-2.
1958	7	-1.	2.	-1.	0.	3.	1.
1959	1	4.	2.	8.	4.	1.	3.
1959	7	1.	1.	1.	-4.	-2.	0.
1960	1	2.	8.	-9.	-2.	1.	4.
1960	7	1.	1.	1.	1.	1.	8.
1961	1	3.	8.	7.	2.	2.	3.
1961	7	0.	1.	-1	-2.	0.	-3.
1962	1	5.	9.	2.	5.	2.	-1.
1962	7	1.	1.	-1.	4.	3.	1.
1963	1	0.	10.	-2.	0.	0.	-1.
1963	7	2.	2.	4.	9.	7.	-2.
1964	1	2.	-1.	-4.	-4.	0.	1.
1964	7	0.	-2.	-4.	-4.	-2.	-2.
1965	1	3.	-6.	1.	-4.	-2.	-2.
1965	7	-2.	-4.	-2.	0.	-5.	3.
1966	1	-3.	-2.	-2.	-3.	0.	1.
1966	7	3.	2.	2.	-2.	-1.	-4.
1967	1	-3.	-2.	6.	3.	2.	-1.
1967	7	0.	-1.	0.	7.	4.	3.
1968	1	-7.	2.	9.	1.	-1.	-3.
1968	7	-3.	-2.	0.	-1.	-6.	-8.
1969	1	-9.	-11.	-2.	0.	-1.	0.
1969	7	1.	1.	1.	-2.	5.	5.
1970	1	1.	7.	2.	2.	0.	1.
1970	7	2.	0.	1.	-4.	1.	-3.
1971	1	4.	-3.	-2.	-2.	0.	-1.
1971	7	-1.	0.	1.	0.	4.	2.
1972	1	-12.	-6.	1.	2.	-3.	-1.
1972	7	0.	0.	-4.	-1.	-4.	-1.

Table B-2 (continued)

a) Northern Hemisphere (continued)

Sea-Only Data

1949	1	3.	2.	3.	4.	1.	0.
1949	7	0.	1.	2.	2.	1.	-1.
1950	1	-1.	-2.	0.	-1.	0.	0.
1950	7	0.	0.	0.	-2.	-1.	0.
1951	1	1.	-1.	-1.	2.	1.	2.
1951	7	3.	4.	3.	5.	1.	2.
1952	1	2.	4.	3.	3.	2.	2.
1952	7	3.	2.	2.	2.	1.	0.
1953	1	2.	2.	4.	2.	4.	2.
1953	7	4.	3.	2.	1.	3.	4.
1954	1	2.	1.	1.	1.	1.	-1.
1954	7	-1.	-1.	0.	-3.	-1.	-2.
1955	1	0.	-1.	0.	-2.	1.	-1.
1955	7	-3.	-1.	1.	-1.	-2.	-2.
1956	1	0.	-1.	0.	1.	-2.	0.
1956	7	-2.	-3.	-3.	-1.	-1.	0.
1957	1	-2.	0.	0.	0.	0.	1.
1957	7	3.	2.	1.	2.	3.	1.
1958	1	1.	1.	2.	3.	1.	3.
1958	7	1.	2.	3.	1.	2.	0.
1959	1	0.	2.	0.	-2.	1.	0.
1959	7	1.	-1.	0.	1.	3.	2.
1960	1	1.	-1.	0.	-1.	3.	1.
1960	7	2.	2.	1.	-2.	1.	-1.
1961	1	-1.	0.	1.	0.	1.	0.
1961	7	1.	0.	-1.	0.	-1.	-1.
1962	1	0.	1.	-1.	0.	-1.	0.
1962	7	1.	0.	0.	3.	2.	NA
1963	1	0.	-3.	1.	-1.	0.	1.
1963	7	0.	3.	1.	2.	0.	2.
1964	1	3.	3.	1.	0.	-2.	-1.
1964	7	-2.	-4.	-2.	-2.	-1.	-3.
1965	1	-2.	0.	-2.	-2.	-2.	-2.
1965	7	-3.	-1.	-1.	0.	1.	0.
1966	1	1.	0.	-1.	0.	-2.	-1.
1966	7	0.	-1.	-2.	1.	-1.	1.
1967	1	-1.	-1.	-2.	-3.	1.	-1.
1967	7	0.	0.	0.	-3.	0.	-3.
1968	1	-3.	-4.	-3.	-1.	-2.	-1.
1968	7	0.	-1.	-3.	-2.	-1.	1.
1969	1	0.	1.	2.	2.	2.	2.
1969	7	1.	1.	1.	0.	-1.	1.
1970	1	0.	-1.	1.	0.	1.	0.
1970	7	-2.	0.	-1.	1.	-1.	0.
1971	1	-2.	-1.	-2.	-1.	-1.	-2.
1971	7	-1.	-2.	-2.	-2.	-3.	0.
1972	1	-1.	0.	0.	-1.	-1.	1.
1972	7	1.	1.	1.	1.	1.	2.

Table B-2 (continued)

b) Southern Hemisphere

Combined Land/Sea Data

1949	1	1.	1.	0.	-1.	-1.	0.
1949	7	0.	-1.	-2.	1.	-1.	-1.
1950	1	2.	-1.	2.	2.	-4.	2.
1950	7	-1.	-1.	8.	-2.	-1.	0.
1951	1	-4.	-1.	2.	1.	2.	0.
1951	7	0.	1.	-3.	0.	-1.	0.
1952	1	1.	2.	2.	-3.	-4.	2.
1952	7	2.	1.	2.	0.	0.	0.
1953	1	0.	1.	0.	-4.	0.	0.
1953	7	0.	2.	2.	0.	1.	0.
1954	1	-1.	0.	0.	-1.	-1.	-4.
1954	7	-2.	-5.	-5.	-1.	1.	0.
1955	1	0.	0.	-1.	1.	2.	-2.
1955	7	0.	3.	1.	1.	-1.	-2.
1956	1	-1.	-1.	-1.	1.	1.	4.
1956	7	3.	1.	3.	0.	-2.	0.
1957	1	0.	1.	3.	5.	4.	2.
1957	7	-1.	3.	2.	-1.	2.	1.
1958	1	2.	1.	1.	1.	-2.	-3.
1958	7	1.	-4.	-1.	2.	2.	-1.
1959	1	1.	0.	1.	-1.	2.	0.
1959	7	-2.	-2.	-4.	-1.	0.	1.
1960	1	-2.	-2.	-4.	-2.	-3.	-6.
1960	7	-1.	1.	2.	1.	-3.	-1.
1961	1	-3.	1.	-3.	2.	4.	-1.
1961	7	1.	-1.	0.	1.	0.	1.
1962	1	0.	-2.	0.	1.	0.	5.
1962	7	2.	2.	4.	1.	0.	2.
1963	1	1.	2.	-3.	-1.	1.	4.
1963	7	1.	6.	4.	-2.	-3.	1.
1964	1	-1.	-2.	0.	-4.	-5.	-1.
1964	7	1.	-6.	-3.	-4.	-2.	-1.
1965	1	0.	3.	-1.	0.	2.	2.
1965	7	0.	4.	-2.	-2.	0.	-1.
1966	1	0.	-2.	1.	4.	0.	0.
1966	7	-1.	-2.	0.	-3.	-1.	-1.
1967	1	1.	-1.	-1.	0.	2.	-1.
1967	7	0.	1.	-1.	0.	1.	1.
1968	1	-2.	-1.	1.	1.	-3.	-2.
1968	7	-1.	-1.	-6.	1.	1.	1.
1969	1	3.	1.	3.	0.	1.	1.
1969	7	-2.	-2.	0.	2.	2.	2.
1970	1	1.	2.	1.	2.	-1.	0.
1970	7	4.	0.	5.	3.	4.	1.
1971	1	4.	0.	1.	2.	1.	-1.
1971	7	1.	3.	3.	1.	-1.	-2.
1972	1	-1.	1.	0.	6.	6.	3.
1972	7	1.	5.	7.	4.	8.	6.

Table B-2 (continued)

b) Southern Hemisphere (continued)

Land-Only Data

1949	1	4.	-1.	1.	1.	0.	2.
1949	7	2.	2.	1.	1.	1.	2.
1950	1	-1.	0.	-1.	1.	-1.	3.
1950	7	2.	-1.	-1.	-5.	-3.	-1.
1951	1	-5.	-4.	3.	-1.	3.	2.
1951	7	1.	1.	-2.	2.	2.	1.
1952	1	6.	3.	4.	1.	0.	-3.
1952	7	1.	4.	1.	0.	-3.	2.
1953	1	0.	0.	2.	-1.	-2.	-2.
1953	7	-6.	2.	1.	-2.	2.	3.
1954	1	0.	0.	2.	-2.	-2.	-4.
1954	7	-4.	-3.	-3.	1.	1.	0.
1955	1	1.	0.	-5.	-1.	-1.	0.
1955	7	-3.	2.	1.	-2.	0.	-4.
1956	1	-5.	-1.	0.	-5.	-5.	-6.
1956	7	6.	-9.	2.	-4.	-5.	0.
1957	1	0.	-2.	1.	1.	5.	11.
1957	7	-5.	6.	4.	4.	6.	5.
1958	1	6.	7.	2.	2.	5.	-5.
1958	7	4.	-9.	0.	3.	5.	-11.
1959	1	-1.	5.	6.	9.	10.	0.
1959	7	8.	0.	-7.	-2.	-1.	5.
1960	1	0.	-6.	-13.	-5.	-9.	-8.
1960	7	1.	1.	-1.	4.	-4.	0.
1961	1	-9.	2.	-1.	15.	7.	-3.
1961	7	1.	0.	7.	5.	0.	-1.
1962	1	-4.	0.	-2.	-3.	-8.	1.
1962	7	-3.	-2.	0.	-9.	0.	-1.
1963	1	-1.	-2.	-4.	-6.	-5.	9.
1963	7	4.	21.	15.	-1.	-12.	-2.
1964	1	-2.	-9.	-1.	-9.	-14.	5.
1964	7	5.	-8.	-8.	-10.	-3.	-3.
1965	1	6.	4.	-7.	-1.	5.	0.
1965	7	3.	12.	-9.	3.	1.	-1.
1966	1	-4.	2.	11.	6.	2.	4.
1966	7	5.	-8.	3.	-4.	2.	1.
1967	1	8.	2.	-3.	-6.	8.	-4.
1967	7	5.	3.	3.	2.	2.	3.
1968	1	-2.	2.	6.	-2.	-5.	2.
1968	7	-13.	-6.	-19.	8.	3.	-2.
1969	1	5.	2.	8.	8.	8.	10.
1969	7	-4.	-3.	1.	7.	3.	2.
1970	1	5.	2.	8.	5.	-6.	5.
1970	7	6.	-5.	13.	8.	1.	5.
1971	1	5.	1.	0.	4.	2.	-14.
1971	7	-3.	6.	5.	1.	-2.	2.
1972	1	-1.	3.	-3.	5.	11.	8.
1972	7	-5.	10.	4.	-1.	16.	7.

Table B-2 (continued)

b) Southern Hemisphere (continued)

Sea-Only Data

1949	1	1.	2.	-1.	-1.	-1.	1.
1949	7	1.	0.	-1.	0.	-2.	-1.
1950	1	3.	-1.	2.	3.	-2.	2.
1950	7	-1.	2.	12.	-1.	-1.	0.
1951	1	-4.	-1.	2.	1.	-1.	-2.
1951	7	0.	0.	-1.	0.	-2.	0.
1952	1	1.	2.	1.	-4.	-1.	3.
1952	7	2.	-2.	-1.	1.	1.	0.
1953	1	0.	1.	0.	-2.	4.	2.
1953	7	2.	0.	2.	0.	1.	-1.
1954	1	-1.	0.	0.	0.	-1.	-3.
1954	7	0.	0.	-1.	-4.	0.	-1.
1955	1	0.	0.	0.	1.	1.	-4.
1955	7	-2.	1.	0.	0.	-1.	-1.
1956	1	0.	-1.	-1.	1.	-1.	0.
1956	7	-3.	0.	3.	1.	-2.	0.
1957	1	0.	1.	3.	5.	3.	0.
1957	7	0.	2.	0.	-1.	1.	0.
1958	1	1.	0.	0.	1.	-2.	1.
1958	7	2.	-1.	1.	2.	1.	2.
1959	1	1.	-1.	0.	-4.	0.	0.
1959	7	0.	0.	0.	0.	1.	0.
1960	1	-2.	0.	-2.	-1.	-2.	-4.
1960	7	-2.	1.	2.	0.	-2.	0.
1961	1	-1.	0.	-4.	-2.	2.	-1.
1961	7	1.	-1.	-2.	0.	-1.	2.
1962	1	1.	-2.	0.	2.	2.	4.
1962	7	4.	4.	2.	2.	1.	NA
1963	1	2.	3.	-3.	0.	2.	2.
1963	7	-1.	2.	2.	1.	0.	1.
1964	1	0.	0.	0.	-3.	-2.	-3.
1964	7	0.	-2.	-1.	-4.	-3.	0.
1965	1	-1.	2.	1.	0.	-2.	1.
1965	7	0.	2.	-1.	-2.	1.	-2.
1966	1	1.	-3.	-2.	4.	-1.	0.
1966	7	-2.	0.	-2.	-2.	-2.	-2.
1967	1	-1.	-1.	-1.	1.	2.	-1.
1967	7	-3.	0.	-2.	1.	1.	0.
1968	1	-1.	-2.	0.	2.	-3.	-4.
1968	7	2.	-1.	-2.	-2.	1.	2.
1969	1	2.	1.	1.	-3.	0.	-1.
1969	7	0.	-1.	-1.	2.	3.	2.
1970	1	0.	2.	-1.	2.	1.	-1.
1970	7	1.	3.	1.	1.	4.	0.
1971	1	4.	-1.	1.	1.	1.	0.
1971	7	3.	-1.	3.	0.	-2.	-2.
1972	1	-1.	1.	2.	4.	2.	1.
1972	7	2.	1.	4.	3.	4.	5.

Table B-3. Monthly Surface Air Temperature Anomalies for the Tropical/ Extra-Tropical Regions, January 1949 to December 1972 (^{o}C x 10).

a) Northern Extra-Tropics

Combined Land/Sea Data

1949	1	5.	-1.	4.	3.	2.	-1.
1949	7	0.	1.	2.	3.	5.	-1.
1950	1	-7.	-3.	4.	-1.	2.	2.
1950	7	0.	-1.	1.	1.	-3.	3.
1951	1	-4.	-5.	-2.	4.	2.	1.
1951	7	1.	3.	4.	3.	1.	3.
1952	1	2.	5.	-2.	4.	2.	3.
1952	7	4.	3.	3.	1.	0.	1.
1953	1	4.	6.	8.	10.	5.	4.
1953	7	6.	3.	3.	3.	4.	5.
1954	1	-4.	0.	0.	1.	1.	1.
1954	7	2.	1.	3.	2.	7.	1.
1955	1	8.	-1.	-3.	-2.	2.	1.
1955	7	-1.	1.	2.	3.	-2.	-5.
1956	1	2.	-4.	-2.	-2.	-3.	1.
1956	7	-1.	-3.	-5.	-3.	0.	1.
1957	1	-1.	5.	1.	-1.	-1.	1.
1957	7	2.	1.	1.	0.	3.	1.
1958	1	6.	2.	1.	-2.	1.	0.
1958	7	0.	2.	1.	0.	2.	0.
1959	1	1.	2.	5.	0.	0.	1.
1959	7	0.	1.	0.	-2.	3.	1.
1960	1	2.	3.	-6.	-2.	4.	3.
1960	7	3.	1.	2.	-1.	3.	5.
1961	1	0.	5.	4.	1.	0.	2.
1961	7	1.	1.	0.	0.	1.	-2.
1962	1	4.	7.	2.	4.	1.	-1.
1962	7	1.	1.	0.	4.	2.	1.
1963	1	2.	3.	-1.	0.	0.	-1.
1963	7	1.	2.	1.	6.	2.	-1.
1964	1	2.	1.	-2.	-3.	-2.	-1.
1964	7	-1.	-3.	-3.	-3.	-2.	-1.
1965	1	2.	-3.	1.	-3.	-2.	-2.
1965	7	-4.	-4.	-3.	-1.	-3.	1.
1966	1	-4.	-3.	-2.	-3.	-1.	0.
1966	7	0.	0.	-1.	-1.	-2.	-2.
1967	1	-2.	-3.	4.	1.	3.	-1.
1967	7	1.	0.	1.	4.	2.	0.
1968	1	-5.	-1.	4.	2.	-1.	-2.
1968	7	-3.	-3.	-3.	-3.	-7.	-7.
1969	1	-6.	-8.	-4.	-1.	0.	-1.
1969	7	1.	1.	1.	-2.	0.	2.
1970	1	-1.	2.	1.	0.	0.	0.
1970	7	-1.	0.	0.	-1.	0.	-2.
1971	1	2.	-1.	-1.	0.	1.	-1.
1971	7	-1.	0.	1.	0.	0.	3.
1972	1	-6.	-3.	2.	0.	-4.	0.
1972	7	-2.	-2.	-3.	-2.	-4.	-1.

Table B-3 (continued)

a) Northern Extra-Tropics (continued)

Land-Only Data

1949	1	8.	-5.	3.	2.	2.	-1.
1949	7	-1.	1.	2.	3.	8.	-3.
1950	1	-12.	-4.	4.	-2.	2.	1.
1950	7	-2.	-3.	2.	3.	-8.	3.
1951	1	-7.	-9.	-2.	5.	3.	-3.
1951	7	0.	3.	5.	1.	2.	8.
1952	1	4.	6.	-6.	4.	1.	2.
1952	7	3.	3.	4.	-2.	-5.	1.
1953	1	6.	9.	9.	10.	4.	5.
1953	7	5.	3.	2.	5.	1.	7.
1954	1	-11.	-1.	0.	-2.	0.	3.
1954	7	3.	3.	4.	5.	11.	2.
1955	1	15.	-1.	-7.	-2.	1.	1.
1955	7	2.	3.	2.	5.	-4.	-7.
1956	1	1.	-13.	-4.	-6.	-3.	0.
1956	7	-2.	-4.	-5.	-4.	-4.	-3.
1957	1	-1.	7.	1.	-1.	-2.	1.
1957	7	1.	1.	2.	-2.	2.	6.
1958	1	12.	6.	1.	-2.	3.	-3.
1958	7	-1.	2.	-2.	-1.	2.	0.
1959	1	4.	3.	10.	4.	1.	3.
1959	7	1.	2.	1.	-5.	-3.	0.
1960	1	2.	10.	-10.	-2.	1.	5.
1960	7	1.	0.	1.	0.	2.	9.
1961	1	3.	12.	10.	2.	1.	4.
1961	7	0.	2.	0.	-2.	2.	-2.
1962	1	8.	12.	3.	7.	3.	-2.
1962	7	0.	1.	-1.	4.	2.	1.
1963	1	-1.	11.	-2.	1.	0.	-2.
1963	7	3.	2.	4.	11.	10.	-3.
1964	1	1.	-1.	-7.	-6.	0.	1.
1964	7	1.	-2.	-4.	-4.	-1.	-2.
1965	1	4.	-8.	2.	-4.	-2.	-2.
1965	7	-3.	-5.	-3.	-1.	-5.	4.
1966	1	-6.	-3.	-2.	-4.	0.	2.
1966	7	2.	1.	2.	-3.	-2.	-6.
1967	1	-2.	-3.	9.	3.	3.	-1.
1967	7	1.	-1.	0.	10.	6.	4.
1968	1	-7.	4.	13.	4.	1.	-2.
1968	7	-4.	-4.	-1.	-2.	-9.	-12.
1969	1	-12.	-16.	-6.	-1.	-2.	-2.
1969	7	0.	1.	0.	-3.	6.	5.
1970	1	0.	7.	2.	2.	-1.	0.
1970	7	2.	0.	1.	-5.	2.	-3.
1971	1	6.	-4.	-3.	-3.	1.	-1.
1971	7	-1.	1.	2.	1.	6.	4.
1972	1	-15.	-6.	1.	2.	-4.	-1.
1972	7	-2.	-2.	-7.	-3.	-6.	-3.

Table B-3 (continued)

a) Northern Extra-Tropics (continued)

Sea-Only Data

1949	1	4.	3.	5.	4.	3.	0.
1949	7	0.	0.	3.	4.	2.	-1.
1950	1	-2.	-1.	1.	0.	1.	2.
1950	7	2.	1.	1.	-2.	0.	1.
1951	1	3.	0.	-3.	3.	0.	3.
1951	7	3.	4.	3.	5.	0.	1.
1952	1	2.	4.	3.	4.	1.	3.
1952	7	5.	3.	2.	3.	1.	-1.
1953	1	3.	2.	6.	2.	5.	1.
1953	7	7.	3.	3.	2.	3.	5.
1954	1	2.	1.	2.	1.	3.	-1.
1954	7	1.	-1.	1.	-1.	1.	-2.
1955	1	1.	-1.	1.	-2.	4.	0.
1955	7	-2.	0.	2.	0.	-2.	-2.
1956	1	2.	1.	0.	0.	0.	3.
1956	7	0.	-3.	-4.	0.	0.	1.
1957	1	-3.	0.	-1.	0.	-1.	0.
1957	7	3.	1.	1.	1.	3.	-1.
1958	1	-1.	-2.	0.	1.	-1.	2.
1958	7	0.	1.	3.	1.	3.	0.
1959	1	-3.	2.	1.	-3.	1.	-1.
1959	7	1.	-1.	0.	1.	5.	2.
1960	1	0.	-2.	0.	-1.	5.	2.
1960	7	4.	2.	3.	-3.	2.	-2.
1961	1	-2.	1.	1.	0.	1.	1.
1961	7	2.	1.	-1.	1.	1.	-2.
1962	1	0.	2.	-1.	0.	-2.	0.
1962	7	1.	0.	1.	3.	3.	NA
1963	1	1.	-5.	1.	-2.	0.	1.
1963	7	-1.	3.	0.	2.	-3.	1.
1964	1	4.	4.	2.	1.	-3.	-2.
1964	7	-2.	-5.	-2.	-1.	0.	-1.
1965	1	0.	1.	-1.	-2.	-2.	-2.
1965	7	-4.	-2.	-3.	-1.	-1.	-1.
1966	1	0.	-4.	-2.	-2.	-3.	-2.
1966	7	-1.	-1.	-3.	1.	0.	2.
1967	1	-1.	0.	-1.	-3.	1.	-1.
1967	7	1.	1.	2.	-3.	1.	-3.
1968	1	-4.	-4.	-3.	0.	-2.	-1.
1968	7	-2.	-2.	-4.	-4.	-1.	0.
1969	1	-3.	-1.	0.	0.	0.	1.
1969	7	0.	1.	2.	-1.	-3.	-1.
1970	1	-2.	-3.	-1.	-1.	0.	-1.
1970	7	-3.	0.	0.	3.	-1.	1.
1971	1	0.	1.	-1.	1.	1.	-1.
1971	7	0.	0.	-1.	-2.	-3.	2.
1972	1	0.	2.	1.	-1.	-3.	1.
1972	7	-1.	-1.	-1.	-2.	-1.	1.

Table B-3 (continued)

b) Tropics

Combined Land/Sea Data

1949	1	1.	2.	2.	4.	1.	1.
1949	7	1.	1.	1.	0.	0.	-1.
1950	1	0.	-2.	-1.	-2.	-2.	-1.
1950	7	-2.	-2.	-2.	-2.	-2.	-2.
1951	1	-3.	-2.	1.	-1.	1.	1.
1951	7	3.	3.	3.	4.	3.	2.
1952	1	3.	3.	3.	3.	3.	1.
1952	7	1.	1.	0.	0.	1.	2.
1953	1	3.	2.	2.	2.	2.	2.
1953	7	1.	2.	2.	2.	2.	1.
1954	1	0.	1.	0.	-1.	-1.	-2.
1954	7	-2.	-2.	-1.	-2.	-2.	-2.
1955	1	-1.	-2.	-1.	-3.	-3.	-3.
1955	7	-3.	-2.	-2.	-2.	-2.	-4.
1956	1	-4.	-2.	-2.	-1.	-3.	-4.
1956	7	-4.	-3.	-3.	-3.	-3.	-2.
1957	1	-1.	-1.	0.	0.	1.	2.
1957	7	2.	3.	2.	2.	4.	3.
1958	1	5.	4.	4.	4.	3.	3.
1958	7	2.	1.	2.	1.	2.	1.
1959	1	3.	2.	1.	1.	1.	1.
1959	7	1.	-1.	0.	1.	1.	0.
1960	1	1.	0.	0.	-1.	0.	0.
1960	7	-1.	1.	0.	0.	-1.	1.
1961	1	0.	-1.	0.	1.	1.	0.
1961	7	-1.	-1.	-1.	-1.	-2.	-1.
1962	1	-2.	0.	-2.	-1.	-1.	0.
1962	7	1.	0.	0.	1.	1.	1.
1963	1	0.	1.	0.	0.	0.	1.
1963	7	2.	3.	3.	2.	2.	3.
1964	1	3.	2.	1.	0.	-1.	-2.
1964	7	-2.	-2.	-2.	-3.	-4.	-5.
1965	1	-4.	-1.	-2.	-2.	1.	0.
1965	7	0.	1.	1.	1.	1.	1.
1966	1	2.	2.	0.	0.	0.	1.
1966	7	1.	0.	0.	0.	0.	0.
1967	1	-1.	-2.	-3.	-2.	0.	-1.
1967	7	-2.	-2.	-3.	-3.	-2.	-2.
1968	1	-3.	-3.	-4.	-4.	-4.	-2.
1968	7	0.	1.	0.	1.	1.	3.
1969	1	2.	4.	5.	4.	4.	3.
1969	7	2.	1.	1.	2.	2.	3.
1970	1	3.	2.	3.	2.	2.	1.
1970	7	-1.	0.	0.	0.	-1.	-3.
1971	1	-1.	-4.	-3.	-2.	-2.	-2.
1971	7	-1.	-3.	-1.	-3.	-3.	-4.
1972	1	-2.	-1.	-1.	1.	2.	3.
1972	7	5.	4.	4.	4.	5.	6.

Table B-3 (continued)

b) Tropics (continued)

Land-Only Data

1949	1	2.	-2.	3.	2.	1.	1.
1949	7	2.	2.	1.	2.	1.	0.
1950	1	-1.	-3.	-3.	-1.	-2.	0.
1950	7	-2.	-3.	-2.	-5.	-2.	-1.
1951	1	-2.	-3.	2.	-1.	2.	2.
1951	7	3.	3.	3.	4.	1.	-1.
1952	1	6.	3.	4.	3.	3.	2.
1952	7	3.	1.	0.	1.	0.	4.
1953	1	4.	4.	3.	2.	2.	1.
1953	7	-1.	3.	2.	2.	4.	0.
1954	1	2.	3.	2.	1.	0.	-2.
1954	7	-3.	-2.	0.	-1.	1.	0.
1955	1	1.	1.	-1.	-2.	0.	0.
1955	7	-1.	0.	-1.	0.	0.	-3.
1956	1	-5.	1.	1.	-2.	-2.	-3.
1956	7	-3.	-3.	-3.	-3.	-1.	-2.
1957	1	-3.	-3.	-3.	-1.	0.	1.
1957	7	2.	2.	2.	3.	6.	5.
1958	1	7.	2.	6.	7.	4.	3.
1958	7	1.	0.	3.	1.	4.	4.
1959	1	3.	1.	2.	3.	2.	3.
1959	7	3.	-2.	-1.	1.	1.	2.
1960	1	1.	1.	-3.	-1.	-2.	2.
1960	7	-1.	3.	1.	2.	0.	5.
1961	1	1.	-4.	-1.	2.	4.	0.
1961	7	-1.	-3.	-1.	-1.	-4.	-4.
1962	1	-4.	-1.	-2.	-1.	-4.	-1.
1962	7	1.	0.	1.	1.	4.	1.
1963	1	1.	3.	-2.	-2.	-1.	1.
1963	7	2.	3.	4.	3.	-1.	1.
1964	1	3.	3.	4.	2.	-1.	-2.
1964	7	-4.	-2.	-3.	-3.	-3.	-4.
1965	1	-2.	0.	-3.	-4.	-1.	0.
1965	7	1.	0.	0.	-1.	-2.	-1.
1966	1	3.	1.	-1.	0.	1.	2.
1966	7	4.	1.	0.	1.	0.	1.
1967	1	-3.	-2.	-4.	0.	1.	-1.
1967	7	-2.	-2.	-2.	-2.	-4.	-1.
1968	1	-3.	-4.	-5.	-6.	-5.	-4.
1968	7	-1.	2.	0.	1.	1.	2.
1969	1	1.	5.	7.	5.	5.	4.
1969	7	2.	3.	3.	2.	3.	3.
1970	1	4.	4.	2.	3.	3.	5.
1970	7	1.	1.	0.	2.	-1.	-2.
1971	1	-4.	-2.	1.	-2.	-2.	-2.
1971	7	0.	-1.	-1.	-4.	-3.	-4.
1972	1	-1.	-1.	0.	1.	1.	2.
1972	7	6.	3.	4.	3.	2.	5.

Table B-3 (continued)

b) Tropics (continued)

Sea-Only Data

1949	1	1.	4.	2.	4.	1.	1.
1949	7	1.	1.	0.	0.	0.	-1.
1950	1	0.	-1.	0.	-2.	-2.	-1.
1950	7	-2.	-1.	-1.	-1.	-2.	-2.
1951	1	-3.	-2.	0.	-1.	1.	0.
1951	7	3.	3.	3.	3.	3.	3.
1952	1	2.	3.	3.	3.	3.	1.
1952	7	0.	1.	0.	0.	1.	1.
1953	1	2.	1.	2.	2.	2.	3.
1953	7	1.	2.	2.	1.	2.	2.
1954	1	0.	0.	-1.	-2.	-2.	-2.
1954	7	-2.	-2.	-1.	-3.	-3.	-3.
1955	1	-1.	-3.	-1.	-3.	-3.	-4.
1955	7	-4.	-3.	-2.	-3.	-3.	-4.
1956	1	-3.	-3.	-2.	-1.	-4.	-4.
1956	7	-4.	-3.	-3.	-3.	-4.	-2.
1957	1	-1.	0.	1.	1.	1.	3.
1957	7	2.	3.	2.	2.	3.	3.
1958	1	4.	4.	4.	4.	3.	3.
1958	7	3.	2.	2.	1.	1.	1.
1959	1	2.	2.	0.	1.	1.	0.
1959	7	1.	-1.	0.	2.	1.	0.
1960	1	1.	0.	1.	0.	0.	0.
1960	7	-1.	1.	0.	0.	-1.	0.
1961	1	0.	0.	0.	0.	0.	0.
1961	7	-1.	-1.	-1.	-2.	-2.	0.
1962	1	-1.	0.	-2.	-1.	0.	0.
1962	7	1.	0.	0.	1.	0.	NA
1963	1	0.	1.	0.	1.	1.	1.
1963	7	2.	3.	3.	2.	3.	4.
1964	1	4.	2.	1.	-1.	-1.	-2.
1964	7	-1.	-2.	-2.	-3.	-4.	-5.
1965	1	-4.	-2.	-2.	-1.	1.	0.
1965	7	-1.	1.	1.	1.	2.	2.
1966	1	2.	2.	0.	0.	0.	1.
1966	7	1.	0.	0.	0.	0.	-1.
1967	1	-1.	-2.	-3.	-2.	0.	-2.
1967	7	-2.	-3.	-3.	-4.	-1.	-2.
1968	1	-3.	-3.	-3.	-3.	-3.	-1.
1968	7	0.	0.	0.	1.	1.	3.
1969	1	3.	3.	4.	4.	4.	3.
1969	7	2.	1.	1.	3.	2.	3.
1970	1	2.	2.	3.	2.	1.	0.
1970	7	-2.	-1.	0.	-1.	-2.	-3.
1971	1	-1.	-4.	-4.	-2.	-2.	-2.
1971	7	-2.	-4.	-2.	-2.	-3.	-4.
1972	1	-2.	0.	-1.	1.	2.	3.
1972	7	4.	4.	3.	4.	5.	5.

Table B-3 (continued)

c) Southern Extra-Tropics

Combined Land/Sea Data

1949	1	1.	-3.	-2.	-4.	-3.	-1.
1949	7	-1.	-2.	-3.	1.	-2.	-2.
1950	1	3.	-1.	2.	5.	-5.	4.
1950	7	0.	0.	15.	-2.	-1.	1.
1951	1	-3.	0.	3.	3.	2.	0.
1951	7	-1.	0.	-6.	-1.	-3.	-1.
1952	1	0.	1.	0.	-7.	-8.	2.
1952	7	2.	1.	4.	0.	-1.	-1.
1953	1	-1.	1.	0.	-7.	-1.	-1.
1953	7	-1.	2.	2.	-2.	0.	-1.
1954	1	-2.	0.	1.	1.	0.	-5.
1954	7	-2.	-6.	-8.	-2.	3.	1.
1955	1	1.	1.	-1.	3.	5.	-2.
1955	7	2.	7.	3.	3.	1.	-1.
1956	1	1.	1.	0.	3.	3.	8.
1956	7	7.	4.	7.	2.	-1.	1.
1957	1	0.	1.	4.	7.	6.	1.
1957	7	-3.	3.	2.	-2.	1.	1.
1958	1	0.	-1.	-1.	0.	-4.	-6.
1958	7	0.	-7.	-3.	3.	3.	-3.
1959	1	0.	0.	0.	-3.	2.	0.
1959	7	-4.	-2.	-6.	-3.	-1.	1.
1960	1	-2.	-3.	-7.	-3.	-5.	-9.
1960	7	-2.	2.	3.	2.	-5.	-1.
1961	1	-5.	1.	-5.	2.	6.	-1.
1961	7	1.	-1.	0.	3.	0.	2.
1962	1	0.	-2.	1.	2.	0.	7.
1962	7	3.	4.	6.	1.	0.	4.
1963	1	2.	3.	-4.	-3.	1.	6.
1963	7	1.	8.	5.	-5.	-6.	-1.
1964	1	-3.	-5.	-1.	-6.	-7.	1.
1964	7	3.	-8.	-4.	-4.	-2.	2.
1965	1	3.	5.	-1.	0.	2.	3.
1965	7	0.	5.	-4.	-3.	0.	-3.
1966	1	-1.	-3.	2.	7.	1.	0.
1966	7	-2.	-3.	-1.	-4.	-1.	-2.
1967	1	1.	0.	0.	0.	4.	-1.
1967	7	2.	3.	0.	2.	3.	2.
1968	1	-1.	0.	4.	3.	-3.	-2.
1968	7	-2.	-2.	-9.	1.	2.	0.
1969	1	3.	1.	3.	-2.	0.	-1.
1969	7	-4.	-4.	-1.	2.	2.	2.
1970	1	1.	2.	0.	2.	-2.	0.
1970	7	7.	0.	8.	5.	7.	3.
1971	1	6.	2.	3.	3.	2.	-1.
1971	7	1.	5.	4.	4.	1.	0.
1972	1	0.	1.	1.	8.	7.	3.
1972	7	-1.	5.	9.	3.	9.	5.

Table B-3 (continued)

c) Southern Extra-Tropics (continued)

Land-Only Data

1949	1	5.	-3.	-2.	2.	0.	4.
1949	7	2.	2.	2.	-1.	1.	2.
1950	1	-1.	2.	2.	4.	3.	6.
1950	7	3.	2.	-1.	-5.	-6.	0.
1951	1	-6.	-4.	3.	-2.	4.	4.
1951	7	0.	0.	-5.	0.	3.	0.
1952	1	5.	1.	2.	-2.	-3.	-6.
1952	7	0.	5.	0.	-3.	-5.	-2.
1953	1	-2.	-4.	1.	-7.	-6.	-6.
1953	7	-12.	1.	2.	-4.	-1.	4.
1954	1	-2.	-1.	2.	-5.	-6.	-5.
1954	7	-5.	-6.	-8.	2.	2.	2.
1955	1	2.	0.	-8.	1.	-1.	-2.
1955	7	-6.	3.	2.	-5.	-2.	-5.
1956	1	-6.	1.	0.	-8.	-8.	-10.
1956	7	13.	-15.	6.	-7.	-7.	2.
1957	1	2.	-3.	2.	1.	8.	18.
1957	7	-9.	9.	6.	6.	6.	7.
1958	1	6.	8.	-1.	-1.	5.	-11.
1958	7	4.	-14.	-2.	3.	6.	-21.
1959	1	-4.	7.	8.	14.	14.	-2.
1959	7	10.	0.	-12.	-5.	-2.	6.
1960	1	-2.	-10.	-22.	-7.	-12.	-15.
1960	7	3.	1.	-1.	7.	-7.	-2.
1961	1	-16.	3.	-3.	25.	10.	-4.
1961	7	1.	2.	10.	9.	1.	-2.
1962	1	-6.	-1.	-3.	-5.	-9.	2.
1962	7	-5.	-4.	-1.	-16.	-2.	-1.
1963	1	-1.	-2.	-5.	-9.	-7.	16.
1963	7	5.	34.	24.	-5.	-18.	-3.
1964	1	-5.	-18.	-2.	-15.	-23.	11.
1964	7	13.	-12.	-12.	-14.	-2.	-2.
1965	1	12.	7.	-9.	1.	9.	0.
1965	7	5.	21.	-14.	7.	2.	-1.
1966	1	-8.	2.	19.	10.	3.	4.
1966	7	7.	-13.	6.	-7.	3.	1.
1967	1	14.	5.	-3.	-10.	12.	-7.
1967	7	9.	6.	5.	4.	6.	7.
1968	1	-3.	6.	14.	0.	-5.	8.
1968	7	-22.	-9.	-31.	13.	6.	-2.
1969	1	9.	2.	12.	10.	9.	15.
1969	7	-8.	-7.	0.	11.	2.	4.
1970	1	7.	1.	12.	7.	-12.	5.
1970	7	10.	-10.	21.	12.	1.	10.
1971	1	10.	4.	-1.	7.	4.	-23.
1971	7	-8.	10.	9.	4.	-2.	4.
1972	1	-1.	4.	-5.	9.	17.	12.
1972	7	-13.	16.	6.	-3.	26.	8.

Table B-3 (continued)

c) Southern Extra-Tropics (continued)

Sea-Only Data

1949	1	0.	-1.	-2.	-4.	-4.	0.
1949	7	1.	-1.	-1.	-1.	-2.	-2.
1950	1	4.	-1.	2.	5.	-2.	3.
1950	7	0.	3.	22.	-2.	0.	1.
1951	1	-3.	0.	3.	2.	-2.	-3.
1951	7	-1.	-2.	-3.	-1.	-5.	-2.
1952	1	0.	1.	-1.	-7.	-3.	4.
1952	7	2.	-4.	0.	1.	0.	-1.
1953	1	-1.	1.	0.	-4.	6.	2.
1953	7	3.	-2.	2.	-1.	1.	-2.
1954	1	-2.	0.	0.	2.	0.	-3.
1954	7	1.	2.	-1.	-6.	2.	1.
1955	1	1.	1.	0.	3.	3.	-4.
1955	7	-2.	3.	1.	2.	0.	0.
1956	1	2.	1.	0.	4.	0.	4.
1956	7	-2.	3.	6.	4.	0.	1.
1957	1	0.	2.	4.	6.	4.	-2.
1957	7	-1.	2.	-1.	-2.	0.	-1.
1958	1	-1.	-2.	-1.	0.	-4.	1.
1958	7	1.	-2.	1.	2.	1.	3.
1959	1	1.	-2.	-2.	-7.	0.	0.
1959	7	-1.	0.	-1.	-1.	0.	0.
1960	1	-3.	-1.	-3.	-1.	-3.	-7.
1960	7	-3.	1.	3.	1.	-4.	-1.
1961	1	-1.	0.	-6.	-2.	4.	-2.
1961	7	2.	-1.	-3.	1.	-1.	3.
1962	1	2.	-2.	2.	4.	4.	7.
1962	7	6.	6.	3.	4.	2.	NA
1963	1	2.	4.	-4.	-1.	3.	2.
1963	7	-3.	1.	1.	0.	-2.	-1.
1964	1	-2.	-1.	-1.	-4.	-2.	-2.
1964	7	0.	-1.	0.	-4.	-2.	2.
1965	1	1.	4.	1.	0.	-4.	1.
1965	7	-1.	2.	-2.	-3.	1.	-4.
1966	1	1.	-5.	-2.	6.	-1.	0.
1966	7	-2.	0.	-3.	-4.	-3.	-2.
1967	1	-1.	-1.	0.	3.	4.	0.
1967	7	-4.	1.	0.	4.	2.	1.
1968	1	-1.	-1.	1.	4.	-2.	-5.
1968	7	3.	-1.	-3.	-4.	0.	1.
1969	1	1.	0.	0.	-6.	-2.	-3.
1969	7	-1.	-3.	-2.	1.	3.	2.
1970	1	0.	2.	-3.	2.	2.	0.
1970	7	4.	6.	2.	1.	8.	2.
1971	1	5.	1.	4.	2.	3.	1.
1971	7	6.	1.	5.	2.	0.	0.
1972	1	0.	0.	3.	5.	2.	-2.
1972	7	1.	-2.	3.	2.	2.	4.

ABBREVIATIONS AND SYMBOLS*

ATW	Air Temperature for the World (Japan Meteorological Agency, 1975)
CMC	Canadian Meteorological Centre
CORREL	correlation coefficient (between land-only and sea-only data)
^{o}	degrees latitude or longitude
^{o}C	degrees Centigrade
^{o}N	degrees North latitude
^{o}S	degrees South latitude
DW	Durbin-Watson statistic (e.g., see Beals, 1972)
FRG	Deutscher Wetterdienst, Federal Republic of Germany
GARP	Global Atmospheric Research Programme
GGO	U.S.S.R. Main Geophysical Observatory
GL	globe ($90^{o}S$ - $90^{o}N$)
GMT	Greenwich Mean Time
km	kilometer(s)
mb	millibar(s)
MCDW	Monthly Climatic Data for the World (U.S. Department of Commerce, 1961 - present)
MIT	General Circulation Data Library, Massachusetts Institute of Technology (e.g., see Oort and Rasmusson, 1971)
NA,na	not available
NCAR	National Center for Atmospheric Research
NCC	National Climatic Center, National Oceanic and Atmospheric Administration, U.S. Department of Commerce
NH	Northern Hemisphere (0^{o} - $90^{o}N$)
NMC	National Meteorological Center, National Oceanic and Atmospheric Administration, U.S. Department of Commerce
NOB	number of observations (years)
NX	northern extra-tropics ($20^{o}N$ - $90^{o}N$)
r	sample correlation coefficient
R-SQR	r-squared, i.e., the square of the sample correlation coefficient in a linear regression (e.g., see Beals, 1972)

* except those used in Table III.

SAT	surface air temperature
SH	Southern Hemisphere (90°S - 0°)
SLOPE	slope coefficient, i.e., slope of the linear trend line derived using linear regression (e.g., see Beals, 1972)
SMIC	Study of Man's Impact on Climate (1971)
SST	sea surface temperature
STD DEV	standard deviation (sample)
SX	southern extra-tropics (20°S - 90°S)
TDF11	Marine Deck, NCC
TR	tropics (20°S - 20°N)
T-STAT	t-statistic (ratio between the slope coefficient and the standard error of estimate; e.g., see Beals, 1972)
UK	U.K. Meteorological Office
WWR	World Weather Records (Clayton and Clayton, 1927, 1934, 1947; U.S. Department of Commerce, 1959, 1965-68)
yr	year(s)

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